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Evaluation of a Carbon Adsorption/Incineration Control System for Auto Assembly Plants

Radian Corp, Austin, Tex

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FINAL REPORT

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TASK NO. 46

EVALUATION OF A CARBON ADSORPTION/ INCINERATION CONTROL SYSTEM FOR AUTO ASSEMBLY PLANTS

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ABSTRACT

The results of work performed by Radian Corporation under EPA Contract No. 68-02-1319 (Task 46) are presented in this report. The purpose of the work was to determine the technical feasibility and the cost of using carbon adsorption/incineration systems to reduce auto assembly plant hydrocarbon emissions to comply with EPA solvent regulations.

The carbon adsorption/incineration system appears, in general, to be technically feasible and applicable for the control of hydrocarbon emissions from auto assembly plant paint spray booths and paint baking ovens. The solvent removal costs are in the ranges of \$1020 - 1600/ton for paint spray booth emissions and \$540 - 1380/ton for paint baking ovens. These costs are computed for effluent air streams containing averages of 50 ppm and 300 ppm by volume of toluene for paint spray booths and bake ovens, respectively. The costs were based on the equipment and operating expenses for a battery limits plant only. The cost of off-site facilities, which can be substantial, are not included in the solvent removal costs.

Installation costs for battery limit plants range from \$0.5 MM to \$4.7 MM for units to treat from 60,000 to 900,000 scfm of solvent-laden air from paint booths, and from \$0.4 MM to \$3.3 MM for units to treat 10,000 to 250,000 scfm of air from paint bake ovens.

A typical auto assembly plant was defined and a system was designed to treat the solvent-laden air to comply with solvent emission regulations such as Los Angeles' Rule 66 (3000 pound per day from each spray booth and an 85% reduction in solvent emissions from each oven). The estimated capital cost of the battery limits control system was \$4.5 MM, and the solvent removal cost was

determined to be $0.71 per pound of solvent removed. The yearly operating cost was estimated to be $1.47 MM for the battery limits plant.

Upon completion of the final draft of this report, a workshop was held on February 26, 1976 at the EPA Region IX offices in San Francisco. The purpose was to critique the report and to discuss the applicability of carbon adsorption systems for the treatment of auto assembly plant air streams. Representatives from various industries and governmental agencies attended. At the conclusion of the workshop written comments were invited from all the attendees. Those comments which were received have been included in Appendix A of this report.

TABLE OF CONTENTS

Page

1.0 INTRODUCTION 1

2.0 CONCLUSIONS 3

3.0 ORGANIC SOLVENTS: EMISSIONS AND CONTROLS 9
- 3.1 Types of Coatings 12
- 3.2 Solvents 12
- 3.3 Organic Solvent Emission Regulations 14
- 3.4 Auto Assembly Plant Paint Opertions 18

4.0 CARBON ADSORPTION SYSTEMS: PROCESS DESIGN 22
- 4.1 Design Considerations 22
  - 4.1.1 Types of Adsorbers 23
  - 4.1.2 Process Variables 26
  - 4.1.3 Carbon Regeneration 33
- 4.2 Paint Spray Booth Solvent Emission Control. 38
  - 4.2.1 Description of System 38
  - 4.2.2 Equipment Description 39
  - 4.2.3 Case Studies 46
- 4.3 Paint Oven Solvent Emission Control 47
  - 4.3.1 Description of System 47
  - 4.3.2 Equipment Description 50
  - 4.3.3 Other Case Studies 53
- 4.4 Emission Control System for a Typical Auto Assembly Plant 53
  - 4.4.1 System Description 54
  - 4.4.2 Description of Equipment 56
  - 4.4.3 Plot Plan 61

TABLE OF CONTENTS (Cont.)

Page
5.0 PROCESS ECONOMICS 63
  5.1 Cost Data 63
    5.1.1 Equipment Costs 63
    5.1.2 Utility Costs 65
  5.2 Paint Spray Booth Emission Control Systems. 66
  5.3 Paint Oven Emission Control Systems 70
  5.4 Control System for a Typical Auto Assembly Plant 75
  5.5 Sensitivity Study 82

6.0 ENERGY CONSIDERATIONS 90
  6.1 Fuel Requirements 90
  6.2 Fuel Availability 91
  6.3 Energy Recovery 91

7.0 OTHER CONSIDERATIONS 94
  7.1 Plant Size/Land Requirements 94
  7.2 Plant Operations 95

8.0 SUMMARY 96

REFERENCES 97

APPENDIX A Comments from Workshop Participants . 99

1.0 INTRODUCTION

The emission of organic solvent vapors to the atmosphere from operations and processes in which these solvents are used (rather than manufactured) is significant. In studies in the Los Angeles and San Francisco Bay areas, the contribution of organic solvent vapors represents as much as 15-20% of the total organic emissions (CH-275, WO-070). In a 1963 study in the San Francisco Bay Area (WO-070) solvent emissions from surface coating operations made up over half of the total organic solvents issuing to the atmosphere.

Automobile assembly plants are the source of a large volume of organic solvent emissions from paint spray booths and paint baking ovens. An auto assembly plant may emit from 20,000 to 40,000 pounds of organic solvents per day. Large quantities of air are passed through paint spray booths in order to minimize worker exposure to paints and solvents. Thus, while significant quantities of solvents are emitted, they are present in small concentrations in large amounts of air. Typically, concentrations of organic solvents are in the range of 30-300 vppm (ppm by volume) in air from paint booths and 100-500 vppm in the air emitted from paint baking ovens.

In recent years, laws have been enacted requiring reductions in the amount of organic solvents emitted from various sources to the atmosphere. The application of these laws to automobile assembly plant paint operations presents some unique problems because of the very large quantities of air, containing low concentrations of solvents, which must be treated to remove the organic materials. Incineration of some assembly plant air streams has been used, but fuel cost and availability preclude any future large-scale use for high volume streams containing low concentrations of solvents.

The use of carbon adsorption systems, with incineration of the desorbed solvents, has been proposed. The purpose of this study was to determine the cost of installing, operating, and maintaining a carbon adsorption/incineration control system for a typical auto assembly plant using lacquer and enamel paints and employing baking ovens. The study includes an investigation of the fuel cost for adsorption/incineration, energy recovery and utilization alternatives, physical size requirements, and the sensitivity of the cost of the system to various important parameters such as solvent concentration, unit size, and air velocity through the carbon beds.

Conceptual process designs were developed for carbon adsorption/incineration systems to treat air from paint spray booths and paint baking ovens. The costs of these units were determined as a function of the quantity of air to be treated. A typical plant was defined, and the types and sizes of carbon adsorption/incineration systems for this plant were selected. The costs of installing, maintaining, and operating the plant were determined, and the physical size of the plant was estimated.

A workshop was held on February 26, 1976 at the EPA Region IX offices in San Francisco, California. Automobile manufacturers, carbon adsorption equipment manufacturers, and various local, state, and federal environmental agencies were represented. The purpose of the workshop was to discuss the suitability of carbon adsorption systems for use in auto assembly plants and to critique this report. At the conclusion of the workshop, all the participants were invited to submit written comments which would be included in the final version of this report. Several of the attendees did respond, and their comments are included in Appendix A of this document.

The observations are quite detailed and extensive. They represent the viewpoints and reflect the experience of both the automobile companies and the carbon adsorption equipment manufacturers. Their comments are a valuable addition to this report.

2.0 CONCLUSIONS

The results of this investigation support the following conclusions:

1) Technical Feasibility

In general, the use of carbon adsorption/incineration systems for the effective removal of organic solvent vapors from air streams being emitted from paint spray booths and paint baking ovens appears to be technically feasible. The term "technically feasible" is used to indicate that no major technological breakthroughs are required to accomplish the removal of solvent vapor from air as described in this report. There may be some instances in which certain solvents might be difficult to remove by carbon adsorption or in which a solvent, once adsorbed, might be difficult to remove from the carbon using steam regeneration.

2) Cost of Paint Spray Booth Emission Control

- The cost of purchasing and installing a carbon adsorption/incineration system for removal of solvents from spray paint booth air ranges from $0.52 MM for a unit to treat 60,000 scfm of air to $4.7 MM for a plant processing 900,000 scfm. These costs are for battery limits plants installed at ground level in mid-1975. The air stream is assumed to contain 50 ppm (by volume) of toluene. The accuracy of these costs is estimated to be ±30%.

- The annual operating costs for paint spray booth solvent emission control vary from $0.17 MM/year to $1.66 MM/year for the units processing 60,000 scfm and 900,000 scfm of air, respectively. These costs include amortization of the capital cost over a 10 year period at 12% interest. They are based on equipment and utilities requirements for battery limits plants only. The operating costs for off-site facilities are not included.

- The cost of solvent removal with the above systems ranges from $0.51/lb for the 900,000 scfm unit to $0.80/lb for the 60,000 scfm plant.

3) Cost of Paint Baking Oven Emission Control

- Carbon adsorption/incineration systems for controlling solvent emissions from paint baking ovens can be purchased and installed for $0.4 MM to $3.3 MM for units sized to process 10,000 to 250,000 scfm of air, respectively. These costs are for battery limits plants installed in mid-1975 at ground level. The air from the ovens is assumed to be at 370°F and to contain 300 ppm (by volume) of toluene. Again, the accuracy of these costs is estimated at ±30%.

- The operating costs of these plants range from $0.12 MM/year for processing 10,000 scfm of air to $1.48 MM/year for a 250,000 scfm air treatment plant. These costs include amortization of the capital costs over a 10 year period at 12% interest. They are based on equipment and utilities requirements for battery limits plants only. The operating costs for off-site facilities are not included.

- The cost of solvent removal from the air emitted from paint baking ovens with the above systems varies from \$.69/lb for treating 10,000 scfm to \$0.27/lb for processing 250,000 scfm of air containing 300 ppm of toluene.

4) Cost of Treating Air From a Typical Plant

- In a typical auto assembly plant containing four paint booths and 8 baking ovens which are emitting excessive amounts of solvent vapors, the cost of purchasing and installing a carbon adsorption system is about \$4.5 MM. The system is sized to treat 570,000 scfm of solvent-laden air. This cost is for a battery limits plant installed at ground level in mid-1975.

- The cost of operating this system is about \$1.5 MM per year. For a plant operating with two shifts and producing 80 units per hour, the operating cost is equivalent to about \$3.50 - \$4.00 per car. This is equivalent to a solvent removal cost of \$0.71 per pound.

- This recovery system is designed to treat only an amount of effluent air sufficient to reduce solvent vapor emissions below a level of 3000 lb/day of solvent from each spray booth. The solvent emissions from ovens are reduced by 85%. The air to be treated amounts to about 40% of the total air emitted to the atmosphere.

- In some cases, it may be possible to reduce the amount of air to be treated by processing the air streams containing high solvent concentrations and rejecting those of low concentrations.

5) Size of System

Carbon adsorption systems of sufficient size to treat more than about 30% of the air emitted from typical auto assembly plants are larger than any regenerable carbon adsorption system now in existence. The design, construction, and operation of a system of this size requires some extrapolation of existing technology. If widely applied, some strain on material and equipment supplies might be experienced.

6) Solvent Recovery

The recovery of solvents from the air (as contrasted to incineration) is not practical because of the number of solvents present and the difficulty involved in separating them into components of sufficient purity to be acceptable for reuse.

7) Steam Regeneration

Steam was selected as the desorbing or regenerating medium. If the amount of steam required to regenerate the carbon is equivalent to or less than 15 pounds of steam per pound of adsorbed solvent, the amount of heat generated from incinerating the solvent is sufficient to produce the necessary steam. Some additional fuel is required, however, for heatup and control purposes.

8) Heat Recovery

The amount of heat produced in the incineration of solvent is normally more than that required for the production of regeneration steam. This excess heat can be recovered either as additional steam or by direct exchange to heat air for the paint baking ovens. Credit for the recoverable heat was included when determining the operating and solvent removal costs for the cases presented in this report.

9) Land Requirements

The physical size of the required carbon adsorption control systems is quite large. A central system large enough for a typical auto assembly plant would require about 0.5 - 1.0 acres of land.

10) Retrofit of Existing Plants

In retrofitting existing assembly plants with carbon adsorption systems, the location of existing paint booth and oven exhaust ducts with respect to a location available for the adsorption systems will be very important. The cost of collection ductwork and, if necessary, additional blowers could be substantial. In some cases the cost of off-site facilities might approach the cost of the battery limits plant. Since this equipment is outside the battery limits of the carbon adsorption system, the costs are not included in the operating and solvent removal costs.

11) Pilot Studies

In order to determine the applicability of carbon adsorption systems for removal of solvents in specific air streams and to obtain design information, pilot studies will be necessary. These could be accomplished using small package adsorption units.

3.0 ORGANIC SOLVENTS: EMISSIONS AND CONTROLS

The emission of organic solvent vapors from stationary sources contributes significantly to the total organic emissions from all sources. For example, in the Los Angeles and San Francisco Bay areas emissions from solvent usage industries represent from 13 to 22 percent of the total organic emissions (CH-275, WO-070). The amounts of emissions are shown in Table 3.0-1.

It is generally agreed that surface coating is by far the largest end use of solvents, ranging from 30 to 60 percent of the total usage. Solvent consumption by the surface coating industry has been estimated to be from 6 to 8 billion pounds per year (MS-001). Of the end use categories, surface coating operations use the largest quantities of mixed petroleum solvents, both aromatic and aliphatic, as well as significant amounts of the oxygenated solvents (alcohols, ketones, esters).

Recent data from the Bay Area Air Pollution Control District (1969) show that 58 percent of estimated solvent evaporation emissions in the District derive from surface coating operations (MS-001). The bulk of the emissions from surface coating operations results from spray painting and evaporative drying or curing operations. This is evident from Table 3.0-2 which shows that about 62 percent of the emissions from the surface coating industry in the San Francisco Bay Area are derived from spray booths, ovens, and dryers (MS-004).

Table 3.0-1

ESTIMATED EMISSIONS OF ORGANIC VAPORS AND GASES FROM VARIOUS SOURCES

	Emissions in Tons per Calendar Day	
	Los Angeles County, Jan. 1962	San Francisco Bay Area, 1963
Solvent Usage	445	280
Motor Vehicles	1300	1100
Petroleum Refining	85	68
Petroleum Product Marketing	100	83
Petroleum Production	60	-
Others	60	569
Total	2050	2100

SOURCES: CH-275, WO-070

Table 3.0-2

AMOUNTS OF ORGANIC POLLUTANTS EMITTED BY SOURCES WITHIN THE SURFACE COATING INDUSTRY IN THE SAN FRANCISCO BAY AREA (1969)

Source	Organic Emissions, Tons/Day
Spray booths	87.7
Ovens and dryers	34.1
Flowcoaters, dip tanks, washers	3.9
Brushing, rolling, non-industrial spraying	72.0
	197.7

Source: MS-004

3.1 Types of Coatings

There are five general types of surface coatings. These are paint, enamel, varnish, lacquer, and shellac. Paints, enamels, and lacquers are all used in the automobile industry.

Paint is a highly pigmented drying oil thinned with a low solvency power solvent, referred to as a thinner. The drying oil is an unsaturated polymer which oxidizes and polymerizes further in air to form a resinous protective film. It is only partially soluble in the thinner. Natural drying oils have been predominantly used, but the shift is now toward the synthetic types. Enamels are basically the same as paints except that synthetic drying oils are present in higher concentrations.

Applied enamel and paint coatings dry and cure by evaporation of the thinner and by oxidation-polymerization of the drying oil to form the resinous film. In contrast, lacquer vehicles consist of a resin dissolved in a high solvency power solvent. After application, the drying occurs by evaporation of the solvent and deposition of the resin-pigment film. The early lacquers consisted of a cellulose nitrate resin, while the present ones are made with acrylic resins.

3.2 Solvents

Compositions of surface coatings and particularly the amounts of solvents and thinners used vary with the end use and type of application method. Typical compositions of paints, enamels, and lacquers are presented in Table 3.2-1. Volatile organic constituents range from less than 10 percent for high solids content coatings for dip and roller applications to over 70 percent for spray applications of lacquers.

TABLE 3.2-1

TYPICAL COMPOSITIONS OF PURCHASED SURFACE COATINGS (%)

Type Coating	Nonvolatile Portion	Hydrocarbons Aliphatic	Hydrocarbons Aromatic	Alcohols	Ketones	Esters& Ethers
Paint	44	56	-	-	-	-
Enamel	58	10	30	2	-	-
Lacquer	23	7	30	9	22	9

SOURCE: MS-004

Water base paints have volatile organic contents on the order of 2 to 5 percent.

Table 3.2-2 contains a listing of some of the individual solvents and thinners which have been used in the surface coating industry. The thinners are aliphatic hydrocarbons, turpentine, mineral spirits, and naphtha. They are used mainly in paints, enamels, and varnishes. The solvents are the aromatics, alcohols, ketones, ethers, and esters. They are used in varying degrees in enamels and varnishes, but mainly in lacquer and shellac.

3.3 Organic Solvent Emission Regulations

A number of federal, state, and local regulations are currently in existence to control the amount of reactive and unreactive organic pollutants which can be emitted to the atmosphere from various sources. Of particular interest in the control of organic solvent vapor emissions are Rule 66 of Los Angeles County and Regulation 3 of the Bay Area Air Pollution Control District. These two similar regulations are concerned with control of solvent emissions to reduce smog, which is a particularly serious problem in these control districts.

Of particular interest to this study are the specific prohibitive rules dealing with organic solvent emissions. These are illustrated by Rules 66a, 66b, and 66c of the Los Angeles County regulations which are summarized below.

Rule 66a

According to this rule the amount of organic material emitted from processes where solvent-containing materials are heat-cured, baked, or heat polymerized, or where solvents come into contact with flame, is limited to 15 pounds per day. The limit

TABLE 3.2-2
SOLVENTS USED IN THE SURFACE COATING INDUSTRIES

Compound	Molar Volume (Vm) cm³/mol	Boiling Point °F
Dodecane	274	421
Undecane	251	383
Decane	229	345
Butyl Carbitol	213	448
Nonane	207	302
2,6-Dimethyl-4-heptanone	207	334
Diethylcyclohexane	207	
Butylcyclohexane	207	354
1-Methylpentyl acetate	194	
Diethylcyclopentane	192	307
Butylcyclopentane	188	314
Octane	185	257
Butylbenzene	185	361
2-Pinene (turpentine)	184	300
Butyl-2-hydroxy-propanate	183	
Pentyl acetate	174	300
Carbitol	169	393
Heptane	163	208
Ethylcyclohexane	162	269
Isopropylbenzene	162	306
Propylbenzene	162	318
Dimethylcyclohexane	162	246
2-Butoxy-ethanol	160	340
2-ethoxy-ethyl acetate	160	313
1-Methylpropyl acetate	155	
Butyl acetate	152	260
2-Methyl-propyl acetate	155	

SOLVENTS USED IN THE SURFACE COATING INDUSTRIES (Cont.)

Compound	Molar Volume (Vm) cm^3/mol	Boiling Point °F
Diisopropyl ether	152	156
4-Methyl-2-pentanol	150	266
Dimethyl cyclopentane	144	
Ethyl cyclopentane	144	217
2-Hexanone	141	
4-Methyl-2-pentanone	141	242
Xylene	140	291
Ethylbenzene	140	277
Hexane	140	154
4-Methyl-3-penten-2-one	133	266
Propyl acetate	129	214
Isopropyl acetate	129	199
Cyclohexanol	127	321
1-Pentanol	127	279
2-Pentanone	118	215
Cyclohexanone	118	231
Toluene	118	231
Cyclohexane	118	178
Diethyl ether	106	94
Ethyl acetate	106	171
2-Methyl-1-propanol	105	
1-Butanol	105	244
2-Butanol	105	210
Cyclopentane	100	120
1-Nitropropane	97	266
2-Nitropropane	97	248
Butanone	96	175
Benzene	95	176
2-Methoxy-ethanol	92	253

SOLVENTS USED IN THE SURFACE COATINGS INDUSTRIES (Cont.)

Compound	Molar Volume (Vm) cm^3/mol	Boiling Point ^{o}F
2-Propanol	84	180
1-Propanol	84	206
Methyl acetate	83	135
Nitroethane	75	239
Propanone	74	133
Ethanol	61	173
Nitromethane	53	214
Methanol	42	149
2-ethyl hexanol		365
Acetone		133
Methylethylketone		175
Amyl acetate		298
Cellosolve		
Cellosolve acetate		314
Ethanol		173
Naphtha (petroleum)		
Mineral spirits		
Trichloroethylene		189

applies regardless of whether the solvents used in the original material are defined as photochemically reactive or photochemically nonreactive. If the 15 pounds per day limit cannot be achieved, the emissions must be reduced by at least 85 percent.

Rule 66b

A limit of 40 pounds per day is placed on the quantity of photochemically reactive organic material which may be discharged into the atmosphere in any one day from any one article or machine which employs, applies, evaporates, or dries such a solvent. Again, if this limit cannot be reached, an 85 percent reduction in emissions must be achieved.

Rule 66c

According to this rule the discharge of photochemically nonreactive organic solvents from any source must be either reduced by at least 85 percent or reduced to not more than 3000 pounds per day. As will be discussed in later sections of this report, solvent emission regulations of this type can seriously impact the painting operations in automobile assembly plants.

3.4 Auto Assembly Plant Paint Operations

The basic painting operations occurring on the assembly line in automobile and commercial vehicle assembly plants are generally similar. There are many minor variations which are dependent on types of vehicles, paints, and assembly sequences.

In a typical operation, the automobile body passes continuously from the body shop (where the main metal portions of the body are assembled) to the paint operation. In the paint operation the bodies are coated first with a primer and then with a topcoat which may be an enamel or a lacquer. After the body has been painted it continues on to the trimshop where seats, dashboards, linings, etc. are added.

Some or all of the body parts may arrive at the plant covered with a light coat of oil to prevent rust. After assembly the body is wiped with solvent to remove the oil and treated in preparation for painting.

The prime coat may be applied by dip-coating, spray painting, or a combination of both. An electrophoretic process (ELPO) may be used in a dip-coating operation where the car body is passed through a bath containing a water-based primer. As an alternative, or in addition to the ELPO process, the prime coat (solvent or water based) may be sprayed onto the car body either manually or by a combination of manual and automatic operations.

After the primer coat has been applied it is baked onto the body in the first baking oven, where the car body passes through a zone of gradually increasing temperature. Heat is supplied by air which is generally heated by indirect exchange with hot flue gases from natural gas combustion.

The primed auto body is cooled after leaving the prime oven and wet sanded to insure adhesion of the topcoat. The body then continues into the first color booth where the topcoat is sprayed on. This is done manually or by a combination of automatic and manual spraying. The automobile body is then sent to another baking oven to bake or cure the topcoat.

There are other possible sequences and combinations of paint booths and ovens, but the above procedure is generally common to most operations. Other paint spray booths along the assembly line might include tutone booths, parts booths, or repair booths. An assembly plant may contain two or more assembly lines, each with its own series of paint spray booths and baking ovens.

Spray booths are operated with air rates of at least 100 ft^3/min per square foot of booth opening as required by various state and federal laws (MS-004). The flow of air is normally in a vertical downward direction. In some cases (small parts, etc.) where paint can be applied from a single spray source, air may be directed in a horizontal direction away from the spray source. Because of overspray of the paint, particulates consisting of pigments, drying oils, and resins are present in the air exhausted from the paint booths. This air is normally passed through a water wash system to remove the particulates. These particulates are subsequently removed from the water by filtration. In general, the water wash system does not remove significant quantities of solvents from the air.

With the required air rates and the large size of many spray booths, it is evident that very large quantities of air pass through the booths. This air contains solvents in concentrations which are generally in the range of 30-300 vppm (RO-227, CA-288). The volume of air passing through a large spray booth may be as high as 300,000 - 450,000 scfm. Spray booths may have as many as 10 or more exhaust ducts. Thus, even though solvent concentrations may be low, the total amount of solvent emitted may easily exceed the maximum allowable level of 3000 pounds per day as specified in many regulations.

Air volumetric flow rates through the baking ovens are lower than those found in spray booths. The amount of air supplied to the oven is governed by requirements for temperature control and solvent concentrations in the oven. The temperature must permit proper curing and the solvent concentration must remain below the lower explosive limits. Depending on the type of coatings, oven temperatures may range from 200°F to 450°F. At these higher temperatures the resins and other components can release small amounts of high molecular weight vapors. The concentration of solvents in the oven air varies widely, but usually lies between 200 and 2000 ppm.

Solvents used in automotive paints, enamels, and lacquers are numerous. A list of solvents identified with surface coatings is given in Table 3.2-2.

4.0 CARBON ADSORPTION SYSTEMS: PROCESS DESIGN

There are several means of removing organic solvent vapors from air streams. These include incineration, catalytic incineration, scrubbing, and carbon adsorption/incineration. The use of carbon adsorption/incineration systems for processing air which contains relatively low concentrations of solvents appears to be the most feasible (CH-275, GR-193). Carbon adsorption systems are currently in wide use in many industries for solvent removal and/or recovery. In the past most applications were justified on an economic basis through recovery and reuse of valuable solvents. More recently, however, they have come into use as a means of reducing air pollution by controlling organic materials present in gas streams emitted to the atmosphere from many industrial operations.

As part of this study conceptual process designs were developed for carbon adsorption/incineration systems to control auto assembly paint plant solvent emissions. A number of systems and process variables were considered, and designs were completed for treating paint spray booth and paint bake oven air. These items are discussed and described below.

Section 4.1 presents general design considerations, Section 4.2 describes the design of a spray booth control system, and Section 4.3 describes the design of a bake oven control system. The control system design for a typical auto assembly plant is discussed in Section 4.4.

4.1 Design Considerations

Several types of adsorbers, a number of process variables, and several methods of carbon regeneration were considered in selecting and designing the system. These are described in the following sections.

4.1.1 Types of Adsorbers

Horizontal Tanks

These types of systems are commonly used to treat quantities of air in the range of 10,000 - 150,000 scfm (GR-193, LE-206). For illustrative purposes, a schematic flow diagram of a typical two-bed carbon adsorption system for organic solvent removal and recovery is shown in Figure 4.1-1.

Each adsorber consists of a horizontal cylindrical tank containing a horizontal bed of activated carbon. Solvent-laden air is fed to the adsorbing bed where it flows downward through the bed, which may be from 12 to 36 inches deep. After passing through the adsorber, the air is exhausted to the atmosphere. The solvent is adsorbed on the carbon until the bed is saturated with solvent. At this point the flow of solvent-laden air is diverted to the other bed.

Steam is then directed into the adsorber containing the saturated bed. The direction of steam flow is normally upward through the bed, opposite to the flow direction of the solvent-laden air. The steam heats the carbon bed, causing the solvents to desorb and be carried out of the adsorber with the steam. As shown in the Figure 4.1-1, the steam is then condensed, and the solvent (assumed to be water-insoluble) is decanted from the water-solvent system and recovered.

Alternatively, the steam-solvent vapor stream may be sent directly to an incinerator if the solvent is not going to be recovered. This type of system is considered in this study as a means of removing solvent and disposing of it.

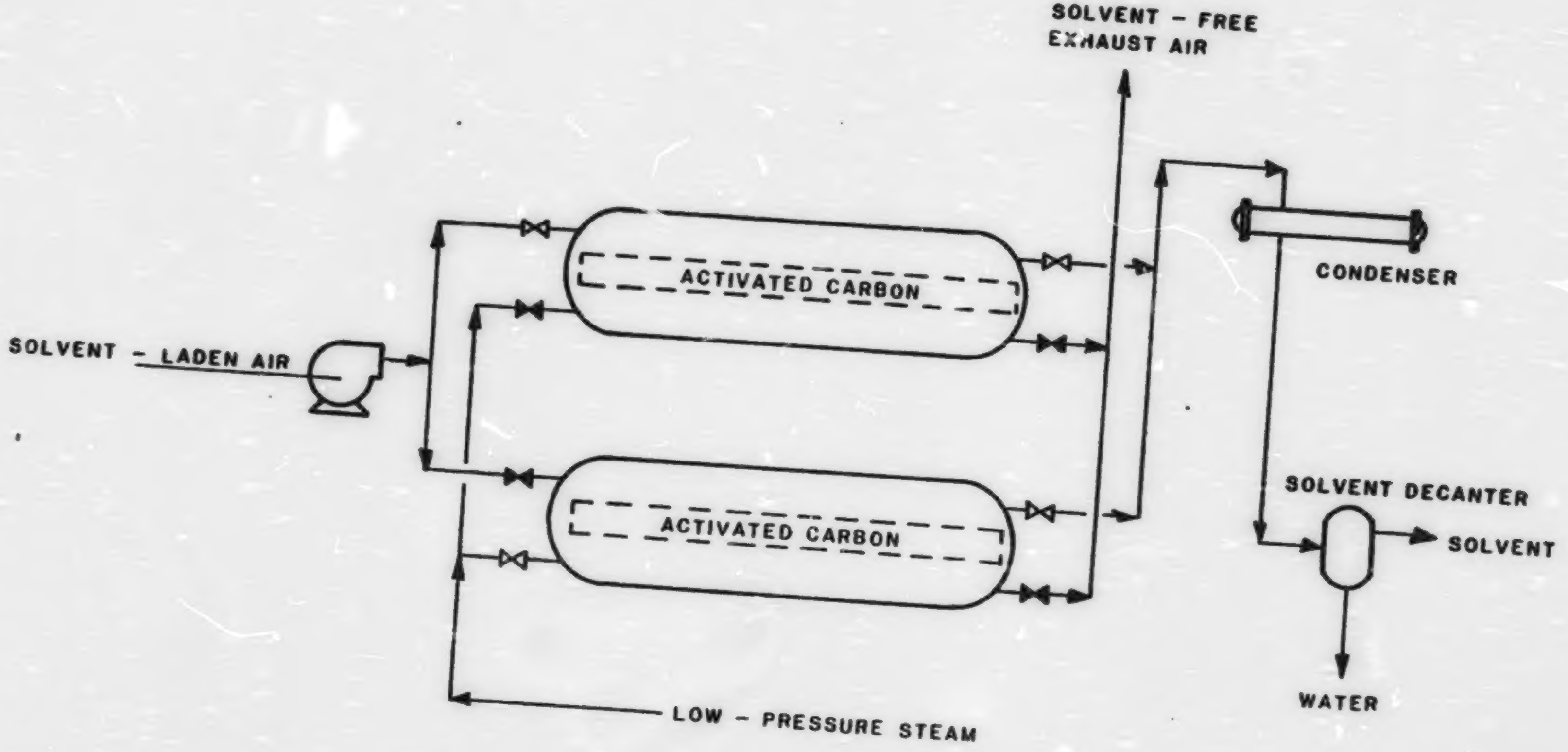
SOLVENT - FREE
EXHAUST AIR
ACTIVATED CARBON
ACTIVATED CARBON
CONDENSER
SOLVENT - LADEN AIR
SOLVENT DECANTER
SOLVENT
WATER
LOW - PRESSURE STEAM

FIGURE 4.1-1
SOLVENT REMOVAL WITH CARBON ADSORPTION SYSTEM

Horizontal adsorbers are generally limited to sizes in the range of 10 feet in diameter by 30 feet long. This size vessel can be shop fabricated and shipped to the plant location.

For larger quantities of air, more adsorbers are added to the system with one or more being regenerated at all times. A system to treat 236,000 scfm of air and employing 10 adsorbers is being planned (GR-193).

Canister Banks

Another type of carbon adsorption bed is the canister. Each canister is cylindrical and consists of an outer shell of activated carbon which may range in thickness from 0.5 to 4 in. The direction of flow of solvent-laden air is from the outside of the canister through the carbon bed and out through the center of the canister.

Individual canisters as large as 14 inches in diameter and 40 inches long are available. This type of canister contains 80-95 pounds of carbon and has the capacity to treat up to 700 scfm of air at a velocity of 75 feet per minute across the bed. These canisters can be mounted in banks of up to 42 in vessels having a diameter of about 10 feet and a height of about 14 feet. Each bank of canisters has a capacity to treat up to 30,000 scfm of air (LE-205).

Vertical Beds

Adsorbers with horizontal beds require a considerable land area if large quantities of air are to be processed. For this reason, large vertical beds were considered as an alternative to horizontal beds for this study. The carbon bed consists of a concentric ring of carbon inside the vessel. The width of the ring (depth of the bed) can be any size, but 12-18 inches was the width selected in this study. A vessel of 20 ft in diameter and 50 ft high with a carbon bed having an inside diameter of 14 ft and an outside diameter of 16 ft can process 225,000 scfm of air with a velocity of 110 ft per minute across the bed. Thus, a system containing 3 such adsorbers can process 450,000 scfm continuously. Approximately 20 horizontal adsorbers would be required to process the same amount of air.

4.1.2 Process Variables

There are a large number of process variables that should be considered in the design of a carbon adsorption system, and the most pertinent of these are discussed below.

Type of Solvent

Many of the solvents associated with the surface coating industries are listed in Table 3.2-2. Included in this Table are the normal boiling points of these compounds and the molar volume, Vm, at the normal boiling point. Compounds of larger molar volume tend to displace those of smaller volume during adsorption on activated carbon. The certainty of displacement increases as the difference in Vm increases (MS-004), so that solvents with small Vm become increasingly difficult to control with activated carbon adsorption systems. Solvents with Vm larger than 80 cm^3/mol offer no real problem, at least in the adsorption phase of the cycle, while problems with those with Vm less than 80 cm^3/mol are variable. The problems of desorption increase significantly with solvents having boiling points above 400°F.

In general, the surface coating industries use hydrocarbons (aromatic, naphthenic, and aliphatic), alcohols, ketones, ethers, glycol ethers, esters, and nitroparaffins. Solvents are used in blends of two to twelve to obtain the desired viscosity, solvency power, drying rate and compatibility with the drying oils and resins. Most frequently, the blends consist of two to five solvents (EN-321, MS-001). The solvents appearing most often in the blends are toluene and xylene.

When the coatings are baked or cured in the baking ovens at temperatures up to 450°F, small amounts of high boiling resins and decomposition products can be volatilized. Unless these are removed prior to entering the adsorption bed, they will be adsorbed. Due to their relatively high molecular weights and boiling points, these compounds may be difficult to desorb using low pressure saturated steam. Superheated steam or hot inert gas may be required.

Some solvents are unstable when in contact with carbon. For example, 4-methyl-2-pentanone can polymerize, thus shortening the carbon bed life. Some ketones decompose and this can create hotspots and subsequent carbon bed fires at high ketone concentrations and/or if proper preventive procedures are not followed.

Solvent Concentration

The solvent concentration range of 1-500 vppm is important for solvent emissions considerations. This concentration range has not been seriously considered in previous solvent removal technology development. Nonregenerative air purification systems may be more practical and economical for treating gases in the concentration range below 10 vppm than regenerative types. Above this range the cost of frequent carbon replacement becomes prohibitive, and regenerative systems are favored.

In general, the efficiency of the carbon adsorption system increases with increasing solvent concentration, since both the absolute and working capacities are greater at higher concentrations. Studies indicate that the economic breakeven concentration for recovering a single, water-insoluble solvent averages about 700 vppm. Around this point the value of the recovered solvent is just about equal to the cost incurred in recovering it (MS-004).

At high solvent concentrations, the heat of adsorption can be high enough to cause a significant rise in bed temperature. This can be sufficient to reduce the adsorptive capacity of the bed and may even cause vapor decomposition. At the relatively low concentrations encountered in most auto plant paint operations, however, the temperature rise should not be great enough to cause any problems.

Multiple Solvents

Air streams containing multiple solvents are treated in many commercial carbon adsorption installations (VU-003, GR-193). The use of mixed solvents does, however, reduce the adsorptive capacity of carbon beds (MS-004) for the individual solvents. Less carbon is required when removing a single solvent at a given concentration than is needed to remove a mixture of solvents with the same combined concentration.

When air containing a mixture of solvents is passed through a bed of carbon, the most strongly adsorbed vapors are separated out in the part of the bed closest to the air inlet. The other solvents are adsorbed in successive bed segments in order of decreasing adsorbability. As the adsorption is continued, the more-strongly adsorbed solvents displace the less-strongly adsorbed ones in the adsorption zone. Depending on the extent of the differences in adsorptivities, either complete displacement or partial displacement accompanied by some coadsorption may occur in the adsorption zone.

The simplest design procedure for processes treating multiple solvents is to assume that each solvent is adsorbed in separate successive beds. This method is conservative and usually results in a bed of excessive depth because of two factors. Coadsorption is generally present in the saturated and adsorption zones. Adsorptive capacities in some zones may increase due to desorption in other zones, which produces an effective rise in vapor concentrations.

Activated Carbon

Activated carbon is the adsorbent most suitable for removing organic vapors (DA-069, MS-004). Carbon adsorbs substantially all the organic vapors from the air at ambient temperatures regardless of variation in concentration. Being generally a non-polar material, carbon selectively adsorbs non-polar vapors. Organic vapors are adsorbed in preference to oxygen, nitrogen, and of particular interest, water. It is generally accepted that compounds with a molecular weight of at least 45 or with a boiling point over 0°C will be well adsorbed on activated carbon (DA-069, GR-193).

Typical granulated activated carbons have high pore volumes of 0.80-1.20 cm^3 per gram and surface areas in the range of 600-1600 m^2 per gram of carbon. The carbons must be strong enough to withstand shear, compressive, and impactive forces encountered in handling and use. Carbons are manufactured from sources such as bituminous coal and coconut shells.

The selection of a carbon adsorbent requires consideration of variables such as types of solvents, solvent concentration, operating conditions (temperature, pressure, humidity, etc.), required removal efficiency, reactivity of solvents on carbon, and contact time.

The ultimate capacity of activated carbon for hydrocarbon vapors is quite high and may exceed .40 cm^3 liquid per gram of carbon at ambient temperatures. The actual working capacity, however, is considerably less than the ultimate capacity and declines with decreasing solvent concentration. The working capacity is the amount of solvent that is repeatedly adsorbed and desorbed during each cycle. It is not economically practical to remove all of the solvent from the adsorbent on each cycle. In general, a carbon can typically be expected to have a working capacity of 5-20 percent of its own weight (MS-004, LE-207, MA-491).

In shallow beds where high efficiencies are required, granulated carbon particles as small as 12-28 mesh size may be used. In deep beds, however, coarser carbons of 4-6, 6-8, or 4-10 mesh size are generally employed to minimize pressure drop, even though a lengthened adsorption zone is required.

Bed Depth

The bed depth depends on the inlet and outlet solvent concentrations, length of adsorption zone, working capacity of the carbon, temperature, number of beds and allowable pressure drop. Bed lengths in solvent recovery/removal systems are normally in the range of 8 to 36 inches. Deeper beds provide more capacity, fewer regenerations, and longer cycle lengths than shallower beds. This advantage must be balanced against the higher pressure drop of deeper beds with correspondingly larger blower and power requirements.

Gas Velocity

The frequency of the adsorption/desorption cycle, the bed dimensions, the solvent removal efficiency, and the resistance to flow must be considered in selecting a gas velocity. Air velocities commonly used in carbon adsorption systems range from 20 to 110 feet per minute (MS-004, LE-205). Velocities above 110 feet per minute cause high resistance to flow, operational problems with valves, extended adsorption zones, and physical attrition of the carbon. The relatively low allowable or practical velocity of the gas across the bed leads to large bed areas and large adsorbers.

Temperature

With most types of solvents and ranges of concentration, the air entering the carbon adsorption bed should not exceed 100°F (GR-193, VU-003). Adsorption should be carried out at a temperature as low as practical because the capacity decreases significantly with relatively small increases in temperature. If the solvent-laden air temperature is above 120°F, it is generally more economical to cool the air than to operate at reduced capacity (LE-205, MS-004). At 120°F, the capacity of carbon is about 75% of the capacity at 77°F. Where air cooling is required the adsorber beds are generally operated at 95-105°F (LE-207, MS-004).

Aging of the carbon bed normally occurs through carbon oxidation. The oxidation rate increases if the adsorbers are operated continuously at temperatures much above 120°F (VU-003).

Humidity

Large amounts of water vapor (a relative humidity of 80% or more) in the solvent-laden air stream interfere with the operation of the carbon adsorption system. After steam regeneration and cooling the bed still contains a considerable amount of moisture. The heat produced by adsorption of solvent on the carbon causes vaporization-of the remaining water from the bed. If the relative humidity of the solvent-laden air stream is high, the water in the bed will not vaporize and water will occupy some sites on the carbon that are normally available for the adsorption solvent. Thus, the working capacity of the bed is reduced.

Particulates

Particulates from paint spray booths consist almost entirely of dried paint particles which escaped capture in the water wash system. Since these materials tend to form coatings on surfaces that they contact, they interfere with the operation of carbon adsorbers. The particulate matter may be deposited on the surfaces of coolers and blowers, causing a decline in operating efficiencies. Periodic cleaning of this equipment is then required. Particulates also plug the carbon adsorption beds, requiring costly replacement of the bed.

The particulate matter may be removed from the air stream with fabric filters made of organic and/or glass fibers. An intermediate or roughing filter may in itself be sufficient to protect the bed. In some cases the intermediate filter should be followed by a high-efficiency filter. Fabric filters are available in many efficiencies, but the cost and resistance to flow increase as the efficiency improves. The initial resistance of intermediate filters is usually between 0.2 and 0.6 inches of water. The resistance rises to 1.0 inch of water as the filter becomes clogged with particulate matter. It is usually replaced at this point.

In a pilot plant study, Chass, et al. (CH-275) found that carbon beds could be adequately protected from both enamel and lacquer paint spray particles by selection of a proper filter system.

4.1.3 Carbon Regeneration

When the carbon bed becomes saturated with adsorbed solvent and the solvent begins to pass through the bed without being completely adsorbed, the carbon is regenerated. This is accomplished by heating the bed to desorb the solvent and sweeping the desorbed solvent vapor from the bed using a clean (solvent-free) gas stream. Steam is generally chosen as the regeneration gas. Hot air or inert gas are also used. These are discussed below.

Steam Regeneration

Most regenerative systems in current use are employed in solvent recovery operations. The most common regenerating agent for this application is steam. In general, steam is a relatively economical means of transferring heat into the bed of charcoal. Enough heat must be supplied to bring the temperature of the carbon up to the desired desorption temperature and to provide the heat of desorption. Steam not only has a very high specific heat, but the heat of condensation of the steam is utilized as it condenses on the adsorbent. It is desirable to operate as close to the dew point of the steam as possible to fully utilize the heat of condensation. In some cases, however, superheated steam is required in order to desorb high boiling solvents.

The amount of steam required for regeneration depends on the operating capacity of the carbon, the cycle length, and the solvent concentration in the solvent-laden air. As desorption of the adsorbed material approaches completion, the steam requirements increase greatly. In order to minimize the steam/solvent ratio, the extent of desorption (working capacity) must be optimized.

As the solvent concentration in the incoming air decreases, the required cycle time and amount of regenerating agent increases. Steam/solvent ratios found in the literature vary widely. A summary of some of these ratios is given in Table 4.1-1. Two to four pounds of steam per pound of desorbed solvent are considered to be optimum ratios (LE-206). The use of 9-12 pounds of steam per pound of solvent is reported for a styrene solvent recovery system (GR-193), but styrene concentrations are not specified. For solvent recovery systems Vulcan Cincinnati literature (VU-003) mentions steam/solvent ratios of 2-10 pounds steam per pound of recovered solvent. In an article describing a system which uses flue gas to regenerate the carbon adsorbent, Mattia states that reducing solvent concentration to 200 vppm can result in steam requirements in excess of 30 pounds per pound of recovered solvent (MA-050). Cannon (CA-288) suggests a steam/solvent ratio of 5.3 pounds per pound to regenerate carbon exposed to air containing 100 vppm of solvent.

TABLE 4.1-1
STEAM/SOLVENT RATIOS FOR CARBON ADSORPTION

Solvent	Solvent Concentration vppm	Steam/Solvent lb/lb	Reference
Varied	Varied	2-4	LE-206
Styrene	-	9-12	GR-193
Varied	Varied	2-10	VU-003
-	200	30	MA-050
-	100	5.3	CA-288
Toluene	150	13	CH-275
-	10	80-400	MS-004

Chass, et al., (CH-275) used an experimentally derived value of 13 pounds steam per pound of recovered toluene in their estimation of the cost of a solvent vapor removal system. The incoming solvent-laden air contained 150 vppm toluene, and the carbon had a working capacity of 8.5 pounds of toluene per pound of carbon.

Some high-boiling compounds may require the use of superheated steam for adequate desorption. The use of superheated steam results in lower steam requirements per pound of solvent due to the higher steam temperature. This is shown in results obtained by MSA Research Corporation (MS-004) in an investigation of the performance of 260°F steam. Superheated steam may also be intermittently used to remove high-boiling compounds which are present in low concentrations in the polluted air and are not completely removed in regenerations with low-pressure saturated steam.

An additional advantage of using steam as the regenerating medium is that the possibility of explosive conditions during the regeneration cycle is prevented.

Air or Inert Gas Regeneration

In some applications where solvent concentrations are low and, in addition, the solvents have little or no recovery value, steam may not be the best regenerating agent. If the quantity of required steam is quite large relative to the amount of adsorbed solvent, it may be more economical in some cases to regenerate with a noncondensable gas such as air or inert flue gas.

Regeneration with hot air does present some problems. The specific heat of hot air is quite low, and large volumes of hot air must be employed to desorb the solvent. Hot air regeneration can create conditions in which there is an ample amount of oxygen present for explosion at elevated temperatures. Furthermore, hot air causes additional oxidation of the carbon, thereby reducing its effective life.

Regeneration with flue gas avoids the problem of potential explosion or combustion in the adsorber. Mattia (MA-050) presented some preliminary studies which indicated that a solvent removal process using flue gas regeneration with subsequent incineration (ZORBCIN Process) is potentially more economical than one employing steam for regeneration with subsequent recovery of the solvent. The complexity of the ZORBCIN system is somewhat greater than the steam regeneration system.

4.2 Paint Spray Booth Solvent Emission Control

Paint spray booth effluent control systems were defined for a base study case. A conceptual process design was developed for this system and is discussed in this section. Major equipment items were selected and sized, and these are described. Variations of the base case design were also investigated.

4.2.1 Description of System

A typical automotive spray paint booth was defined as one which is exhausting 450,000 scfm of solvent-laden air to the atmosphere. The air was assumed to have passed through a water curtain to remove paint particulates, and to be available at 100°F. As mentioned in a previous section of this report, the number of solvents contained in a paint coating may be as high as twelve. It is unnecessary for conceptual design purposes to specify the number, identity, and concentrations of solvents. Toluene was selected as a typical solvent, and a concentration of 50 vppm in the spray booth effluent air was chosen.

A working capacity for the carbon adsorbent was defined as 7 percent by weight (MA-491). The carbon working capacity for toluene is relatively low compared to many other solvents (MA-491). The size selected for the carbon was 6-8 mesh, and the bulk density of the carbon was assumed to be 28 pounds per cubic foot.

Toluene removal efficiency of the carbon bed was assumed to be 90%. Steam was chosen as the regenerating agent for three reasons. Equipment using this regeneration medium is relatively simple. Processes using steam regenerant are in commercial operation. In addition, the danger of explosion is virtually eliminated, even in the event of equipment malfunction.

A carbon life of 4 years was assumed with a stream time of 5500 hours per year. After this time, a fresh charge of carbon is loaded into the adsorbers.

The bases for Case III, the base case, and other cases are summarized in Table 4.2-1.

4.2.2 Equipment Description

A schematic flow diagram for a carbon adsorption system to treat 450,000 scfm of solvent-laden air (SLA) is shown in Figure 4.2-1. Three adsorption vessels are used, each with a concentric or annular bed of carbon. At any given time two of the beds are adsorbing and one is being regenerated. The solvent-laden air enters from the paint spray booth, is filtered to remove particulate matter, and continues on into the SLA blower. This blower provides enough head to move the air through the carbon bed and out the top of the adsorption vessels. In the adsorption vessels, the solvent-laden air enters the outer portion of the vessel, flows horizontally across the carbon bed where solvent is adsorbed, and passes up through the center of the bed to be exhausted to the atmosphere.

During regeneration, steam (15 psig, saturated) is passed through the bed in the direction opposite to that followed by the air. As it passes across the bed, the solvent is desorbed and is carried out of the bed with the steam. After mixing with preheated combustion air and passing through a booster fan which provides enough head to get the vapor into the incinerator, the mixture is incinerated in the incinerator/boiler. There is enough solvent in the vapor (under average desorption conditions) to maintain combustion, but some fuel (gas or oil) is added for control purposes as well as to provide steam until the bed is heated and solvent begins to desorb.

TABLE 4.2-1
BASES FOR DESIGN AND CASE STUDIES

	CASE												
	I	IIA	IIB	III (Base Case Booth)	IV	V	VI	VII	VIII	IX	X	XI (Base Case Oven)	XII
Feed													
Air Source	Booth	Booth	Booth	Booth	Booth	Booth	Booth	Booth	Booth	Oven	Oven	Oven	Oven
Air Temperature, °F	100	100	100	100	100	100	100	100	100	375	375	375	375
Solvent	Toluene												
Solvent Concn., ppm	50	50	50	50	50	50	50	150	300	300	300	300	300
Air Flow Rate, 10³ scfm	60	250	250	450	900	450	450	450	450	10	20	50	250
Adsorption													
Bed Depth, inches	12	12	12	12	12	12	12	12	18	18	18	18	18
Carbon Size, Mesh	6-8												
Max. Air Velocity Across Bed, ft/min	110	110	110	110	110	80	50	110	110	110	110	110	110
Carbon Operating Capacity, wt %	7												
Solvent Removed, %	90												
Carbon Life, years	4	4	4	4	4	4	4	4	4	2	2	2	2
Regeneration Steam													
Steam Pressure, psig	15												
Steam Required lb/ lb solvent	10												
Cycle Length, hr.													
Adsorbing	28	28	14	24	24	36	60	9	6.8	7.5	7.5	7.5	8.0
Regenerating	6	5	6	6	5	6	6	4	3.0	5.0	5.0	3.0	2.0
Cooling	8	2	1	6	1	6	6	0.5	0.4	2.5	2.5	0.8	0.7
Stream Time													
Hours/day	20												
Days/week	6												
Weeks/year	46												
Hours/year	5500												

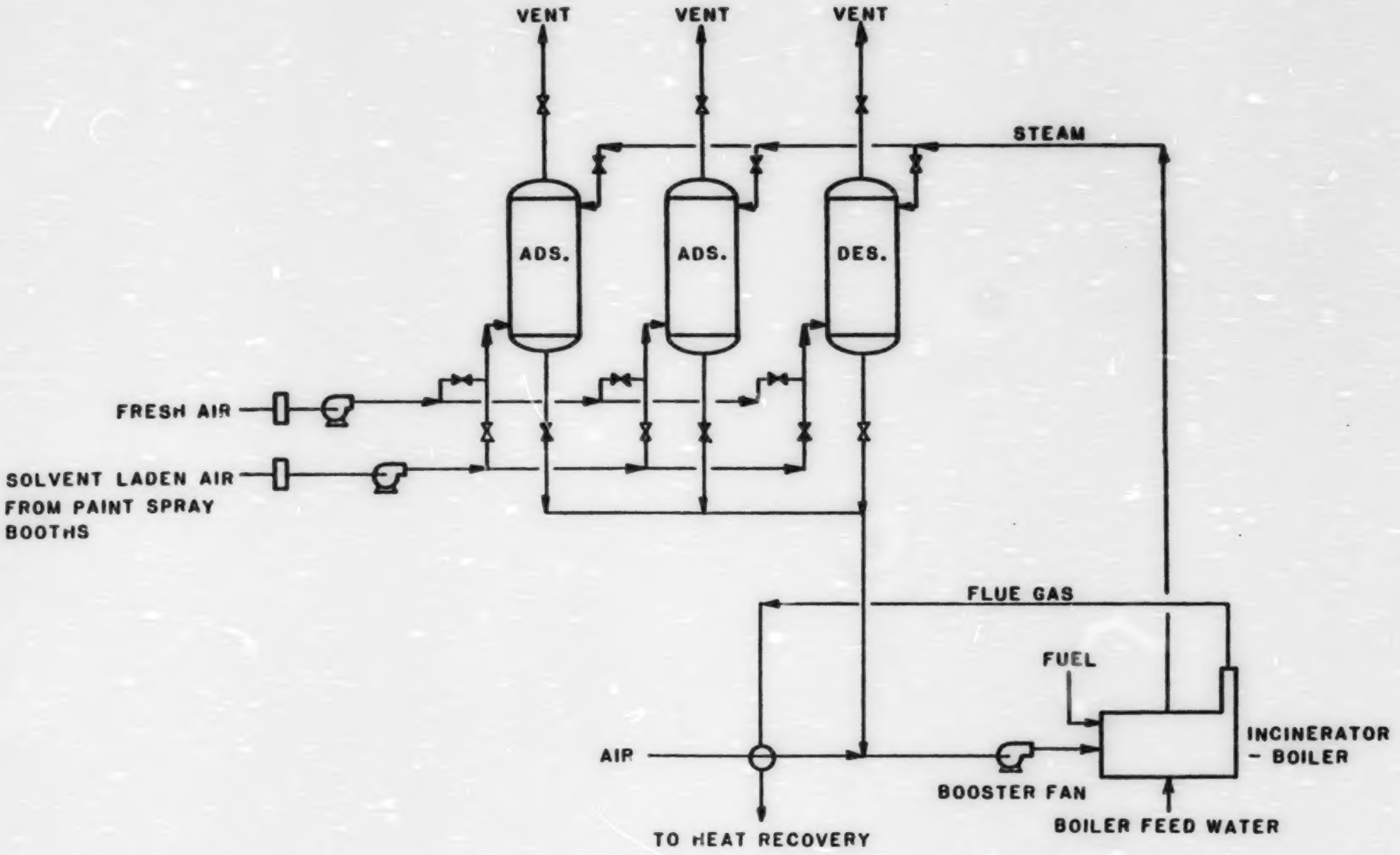
VENT
VENT
VENT
STEAM
ADS.
ADS.
DES.
FRESH AIR
SOLVENT LADEN AIR FROM PAINT SPRAY BOOTHS
FLUE GAS
FUEL
INCINERATOR - BOILER
AIR
BOOSTER FAN
TO HEAT RECOVERY
BOILER FEED WATER

FIGURE 4.2-1

CARBON ADSORPTION SYSTEM FOR PAINT SPRAY BOOTH SOLVENT EMISSION CONTROL

CASE III (BASE CASE): 450,000 SCFM OF SOLVENT - LADEN AIR

Enough steam is generated in the boiler by the incineration to provide the amount required for regeneration. The flue gas from the incinerator is still hot enough to provide heat for: 1) preheating the air required for combustion, and 2) production of additional steam for use in the plant or preheating of the air going to the baking ovens.

The major pieces of equipment are listed in Table 4.2-2. The major equipment items, sized for the Base Case III, are described below. Costs of the major pieces of equipment are included. The bases for these costs are given in Section 5.1

Adsorbers

The shell for each adsorber is a vertical cylindrical vessel. For the Base Case III (450,000 scfm) each adsorber is 50 feet high and 20 feet in diameter. The carbon is enclosed in a concentric or annular bed 12 inches thick. Some solvents are themselves corrosive to mild steel and others decompose during adsorption or regeneration to form corrosive compounds. For this reason the shell is clad with stainless steel and the adsorber internals are constructed of stainless steel. The bed itself is 45 feet high, and the face area of the bed is 2050 square feet.

SLA Blower

The solvent-laden air blower has a capacity of 485,000 cfm of air at 100°F (450,000 scfm). A head of 17 inches of water is sufficient to move the air through the system, including the 12 inches of activated carbon. The blower is sized to operate normally at 80% of its rated capacity with an overall efficiency of 65%. This requires a 2500 horsepower motor. The blower itself is constructed of carbon steel.

TABLE 4.2-2
CARBON ADSORPTION SYSTEM FOR SPRAY BOOTH EMISSION CONTROL CASE III (BASE CASE): EQUIPMENT LIST

1. Adsorbers	Number Required: 3 Size: 20 ft. diameter, 50 ft. high Carbon Bed: Concentric, 12 inches thick, 14 ft. i.d., 16 ft. o.d. Material: Shell - 316 SS clad Internals - 316 SS Cost: $533,000 each (Installed, 1975) $1,599,000 for 3 adsorbers (excl. carbon)
2. SLA Blower	Number Required: 1 Capacity: 485,000 cfm Discharge Head: 17 inches of water Material: Carbon steel Size: 2500 bhp (65% efficiency @ 80% capacity) Cost: $151,000 (installed 1975)
3. Boiler/Incinerator	Number Required: 1 Capacity: 12,000 pounds of steam per hour Steam Condition: 15 psig, saturated Cost: $33,000 (installed, 1975)
4. Control Valves	Number Required: 6 Size: 48 inch Type: Butterfly Material: Carbon steel Cost: $20,000 each (installed, 1975) $120,000 for 6 valves

TABLE 4.2-2 (Continued)

5.	Air Preheater	Number Required: 1 Area: 150 square feet Material: Carbon steel/stainless steel Cost: $24,000 (installed, 1975)
6.	Air Filters	Capacity: 485,000 cfm Type: Disposable fiberglass bag filters Cost: $50,000 (installed, 1975)
7.	Fresh Air Blower	Number Required: 1 Capacity: 2200 scfm Material: Carbon steel Size: 20 bhp Cost: $6000 (installed, 1975)
8.	Incincerator Booster Fan	Number Required: 1 Capacity: 5500 cfm Material: Carbon steel Size: 20 bhp Cost: $6000 (installed, 1975)

Boiler/Incinerator

The boiler/incinerator is assumed to be a "package" type boiler with alterations to permit incineration/combustion of the regeneration stream of solvent and steam and to allow auxiliary firing with gas or oil. The boiler was sized for twice the average required steam rate.

Control Valves

Six 48-inch control valves are required for the air inlet and outlet lines of the three adsorbers. These are carbon steel butterfly-type valves with Teflon seals. They are required to close and remain virtually leak free against a pressure of 30 inches of water. Minimal leakage is required in order to insure that solvent-laden air will not leak into an adsorber during the regeneration cycle. Other valves were not itemized because they are of nominal size and cost.

Air Preheater

A small shell and tube exchanger is required to preheat the combustion air that is mixed with the regeneration stream of steam and solvent. The air is preheated to 220°F to prevent cooling and condensation of the steam in the regeneration stream. The tubes are constructed of stainless steel to prevent damage from any corrosive components that may be present in the regeneration gas. An exchanger with an area of 150 square feet is required.

Air Filters

The solvent-laden air from the paint spray booth will contain fine, dry particles of paint pigment. The actual particulate loading in the air is not known and will depend on the efficiency of the overspray removal system (water curtain, baffles, etc.) and the degree of filtration already present in the assembly plant. It is necessary to keep the carbon bed as free of particulates as possible. There are many types of dry, disposable filter mediums available including felt fabric and glass fabric bags, envelopes, pads, etc. Disposable fiberglass bag filters were selected because of their high efficiency. It was assumed that replacement of these filters would be reqired on a monthly basis A total of 485,000 cfm of air at 100°F must be filtered.

Fresh Air and Incinerator Blowers

Two additional small blowers are required in the process. A fresh air blower is required to blow fresh air through the adsorber after regeneration in order to cool the bed to approximately 100-110°F before the adsorber is placed back in service. The fresh air blower must have a capacity of about 2200 scfm and must provide a discharge head of about 6-8 inches of water. A 10 horsepower motor was selected to drive the blower. The blower itself is constructed of carbon steel.

The incinerator blower is needed in order to boost the pressure of the stream of steam, solvent vapor, and air to a pressure sufficiently high to move the stream through the burner and incinerator. A discharge head of 10-15 inches of water is required. An average of 5500 cfm of gas at 220°F is handled, and a 20 horsepower motor was selected in order to give a reasonable degree of flexibility in handling surges of gas. This blower is also made of carbon steel.

4.2.3 Case Studies

A number of case studies were made. The effect of several major variables on the arrangement, size, and type of process equipment required to treat solvent-laden air from paint spray booths was investigated in Cases I through VIII. The principal variables examined were system size (Cases I-IV), allowable air velocity through the carbon bed (Cases V and VI), and solvent concentration in the solvent-laden air (Cases VII and VIII). The bases for these cases are tabulated in Table 4.2-1.

4.3 Paint Oven Solvent Emission Control

A base case was defined for a carbon adsorption/incineration system to remove solvent vapors from paint oven effluent air. The conceptual process design for the base case as well as other cases is discussed in this section. The size and type of required equipment is described.

4.3.1 Description of System

A base case (Case XI, in Table 4.2-1) was defined for a system to treat 50,000 scfm of solvent-laden air from an auto assembly plant paint oven. The solvent, toluene, is present in the air at a concentration of 300 vppm. A schematic flow diagram for the base case process is shown in Figure 4.3-1. In its basic concept and design, the process is similar to the one developed to treat paint spray booth air. There are some important differences, however.

The air from the paint oven is hot when exhausted. For design purposes, it is assumed to be at 375°F when delivered to the adsorption system. Cooling is required to reduce the temperature of the air to 100°F before it enters the carbon adsorption bed, since the bed will not function efficiently at temperatures much above 100°F.

Small amounts of high boiling materials such as resins, polymers, or plasticizers are generally present in the air from paint ovens. If these components are adsorbed on the carbon,

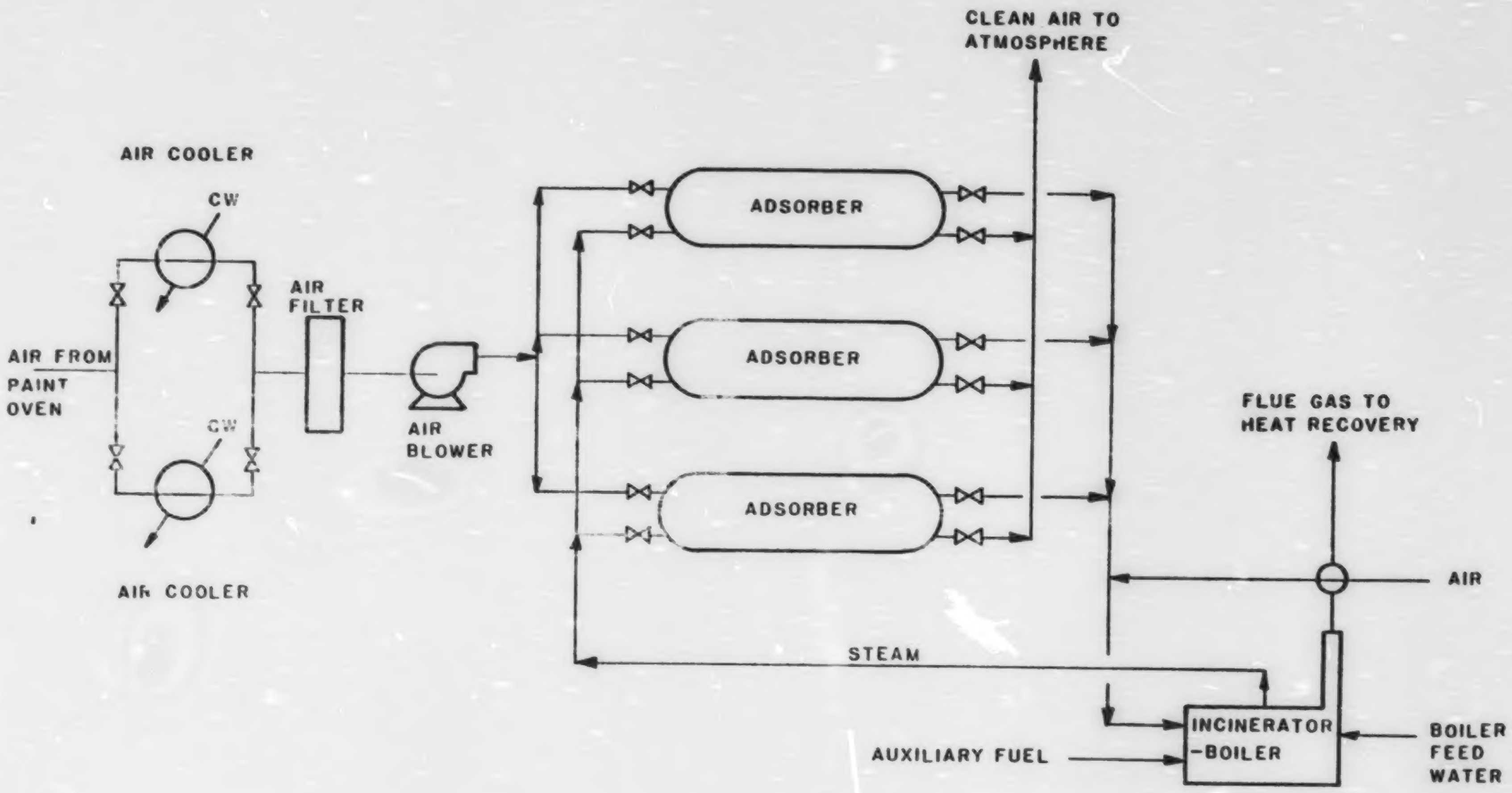
CLEAN AIR TO
ATMOSPHERE
AIR COOLER
CW
AIR FROM
PAINT
OVEN
CW
AIR COOLER
AIR
FILTER
AIR
BLOWER
ADSORBER
ADSORBER
ADSORBER
FLUE GAS TO
HEAT RECOVERY
AIR
STEAM
INCINERATOR
-BOILER
AUXILIARY FUEL
BOILER
FEED
WATER

FIGURE 4.3-1

CARBON ADSORPTION SYSTEM FOR PAINT OVEN SOLVENT EMISSION CONTROL

BASE CASE XI: 50,000 SCFM

removal by steam regeneration is difficult, and the life of the carbon is, therefore, reduced. However, during cooling from 375°F to 100°F in the air coolers, it is very possible that most of the high-boiling components present in the vapor stream will condense and be deposited on the air side of the cooling surface. This will protect the carbon bed to a large extent, but the air coolers will have to be periodically cleaned to remove the condensed heavy materials. For this reason, two exchangers are required. One will be in service while the other is being cleaned. The cooling medium is water available at 75°F and returning to the cooling tower at 90°F.

After being cooled, the solvent-laden air is filtered to remove particulates. It then flows to an air blower which provides the head required to move the air through the entire solvent removal system. The air passes from the blower into the horizontal adsorbers. For this 3-adsorber system, two of the beds are always adsorbing, while the other is undergoing regeneration. The air passes through the horizontal carbon beds and is exhausted to the atmosphere after 90% of the solvent vapors have been removed.

Regeneration is accomplished with steam in the same manner as described in the previous section, and the flow of the regeneration vapor stream is also the same, i.e., from the adsorber to the incinerator/boiler.

The life of the carbon bed was assumed to be only two years due to possible buildup of high boiling materials. After two years a fresh charge of carbon will be required.

The bases for the oven base case, Case XI, and other design cases are given in Table 4.2-1.

TABLE 4.3-1
CARBON ADSORPTION SYSTEM FOR PAINT OVEN EMISSION CONTROL
CASE XI (BASE CASE): EQUIPMENT LIST

1. **Adsorbers**	Number Required: 3 Size: 10 feet diameter, 25 feet length (horizontal) Carbon Bed: Horizontal, 18 inches deep Material: Shell - 316 SS clad Internals - 316 SS Cost: $60,600 each (installed, 1975) $181,000 total (excl. carbon)
2. **Air Coolers**	Number Required: 2 Area: 7400 square feet per exchanger Type: Shell and tube, floating head Material: CS/CS Cost: $158,900 each (installed, 1975) $317,800 total
3. **SLA Blower**	Number Required: 1 Capacity: 54,000 cfm Head: 30 inches of water Material: Carbon steel Size: 500 bhp Cost: $74,800 (installed, 1975)
4. **Boiler/Incinerator**	Number Required: 1 Capacity: 5000 pounds of steam per hour Steam: 15 psig, saturated Cost: $14,300 (installed, 1975)

TABLE 4.3-1 (Cont.)

5. Control Valves	Number Required: 6 Size: 3-30" 3-24" Type: Butterfly Cost: 30" - $12,700 each 24" - $10,000 each $68,100 total (installed, 1975)
6. Air Preheater	Number Required: 1 Area: 50 square feet Material: CS/SS Cost: $9,300 (installed, 1975)
7. Air Filters	Capacity: 80,000 cfm Type: Disposable fiberglass bag filters Cost: $16,000 (installed, 1975)
8. Fresh Air Blower	Number Required: 1 Capacity: 550 scfm Material: Carbon steel Size: 2 bhp Cost: $1800 (installed, 1975)
9. Incincerator Fan	Number Required: 1 Capacity: 2100 cfm Material: Carbon steel Size: 10 bhp Cost: $5300 (installed, 1975)

boiling materials present in the air. The exchangers will require periodic cleaning to remove this material. For this reason two exchangers are required. One will always be in service. Air will be routed through the tubes to facilitate cleaning procedures, since deposits will form in the tubes.

Cooling water, available at 75°F and returned to the cooling tower at 90°F, will be used as the cooling medium. Each exchanger is constructed of carbon steel and contains 7400 square feet of heat exchange surface.

4.3.3 Other Case Studies

The only parameter investigated for its effect on the design and cost of an adsorption system for paint oven emissions was the volume of oven air to be treated. In addition to the base case (Case XI), which was sized for 50,000 scfm of solvent-laden air, three other systems were designed for 10,000, 20,000, and 250,000 scfm of air. The bases for these systems, Cases IX, X, and XII, are given in Table 4.2-1

4.4 Emission Control System for a Typical Auto Assembly Plant

A typical auto assembly plant paint operation was defined. The plant contains two assembly lines (lines A and B), and each of the assembly lines incorporates paint spray booths and paint bake ovens. While as many as 10 spray booths and 10 ovens may be included in each line, it was assumed that solvent emission controls are required on only two booths and four ovens from each line. For compliance with regulations it is required that the emissions from each paint spray booth be reduced to 3000 pounds per day, and that the emissions from the paint ovens be reduced by 85%. This requires total reductions of 6400 and 1150 pounds of solvent per day from the paint spray booths and bake ovens, respectively.

The assumed solvent distribution in the air from the various sources is shown in Table 4.4-1. The solvent concentrations are 50 vppm in air from the spray booths and 300 vppm in air from the paint ovens. Air from the spray booths is available at 100°F from the plant, while the solvent-laden air from the ovens is emitted at 375°F.

4.4.1 System Description

Two large adsorption systems are required to treat the air from the paint spray booths. It was assumed that only enough air would be treated to reduce the emissions rates to allowable levels. These levels were 3000 pounds per day from each spray booth and 85% reduction in the emissions from each oven. A 90 percent solvent removal efficiency is specified. The minimum amount of air to be treated is 320,000 scfm and 170,000 scfm from the spray booths of assembly lines A and B, respectively. To allow for some flexibility, the systems were sized for 350,000 scfm and 200,000 scfm.

The quantity of air to be treated from the paint ovens is considerably less than that from the spray booths. Again, it was assumed that only enough air would be treated to effect the required reductions. The amount of air from the paint ovens that requires treatment is 6300 scfm from line A and 8200 scfm from line B. Both adsorption systems were sized to treat 10,000 scfm.

It is recognized that multiple solvents are present in spray booth and paint oven air, and that the presence of several solvents instead of one could require a somewhat deeper carbon bed to effect proper removal. For design purposes in this case, however, toluene was selected as a representative solvent.

TABLE 4.4-1
PAINT PLANT OPERATIONS OF A TYPICAL AUTO ASSEMBLY PLANT
SUMMARY OF SOLVENT EMISSIONS

Emission Source	Assembly Line	Current Solvent Emissions, lb/day	Proposed Solvent Emission Limits, lb/day	Required Reduction, lb/day
Spray Booth 1	A	5,500	3,000	2,500
Spray Booth 2	A	4,700	3,000	1,700
Spray Booth 3	B	4,900	3,000	1,900
Spray Booth 4	B	3,300	3,000	300
		18,400	12,000	6,400
Oven 1	A	176	26	150
Oven 2	A	118	18	100
Oven 3	A	176	76	150
Oven 4	A	118	18	100
Oven 5	B	235	35	200
Oven 6	B	118	18	100
Oven 7	B	294	44	250
Oven 8	B	118	18	100
		1,353	203	1,150

4.4.2 Description of Equipment

The major equipment items required in the four separate systems are listed in Table 4.4-2.

Adsorbers

The spray booth solvent adsorption systems each consist of three vertical adsorbers, all of which are 20 feet in diameter. The process flow is the same as shown in Figure 4.2-1. The adsorbers treating air from the spray booths in assembly line A are 40 feet high, while those removing solvent from assembly line B spray booths are 30 feet high. Each adsorber contains a concentric or annular bed of carbon which is 12 inches thick. In each system, two adsorbers are adsorbing and one is being regenerated at any given time. The adsorbers are internally clad with 316 stainless steel, and the internals are entirely constructed of 316 stainless steel.

The operating conditions are shown in Table 4.4-3. With the exception of the normal air velocity across the bed, the operating conditions are the same as those of Case IIB shown in Table 4.2-1.

Two horizontal adsorbers, 5 feet in diameter and 18 feet long, are used in each of the oven emission control systems. These vessels are also clad in 316 stainless steel and the vessel internals are made of 316 stainless steel. The carbon beds are 18 inches deep. In each system one bed is adsorbing, and one is undergoing regeneration at any time.

TABLE 4.4-2

SOLVENT REMOVAL SYSTEM FOR A TYPICAL AUTO ASSEMBLY PLANT
MAJOR EQUIPMENT ITEMS

Air Source	Paint Spray Booths		Paint Bake Ovens	
Assembly Line	A	B	A	B
No. of Sources	2	2	4	4
System ID	A1	B1	A2	B2
Rated System Capacity, scfm	350,000	200,000	10,000	10,000
Adsorbers:				
Number	3	3	2	2
Type	Vertical	Vertical	Horizontal	Horizontal
Size: Feet (Diameter X Length or Height)	20 x 40	20 x 30	6 x 18	6 x 18
Air Coolers:				
Number	-	-	2	2
Area, Ft^2/Exchanger	-	-	1,500	1,500
SLA Blower:				
Number	1	1	1	1
bhp	2,000	1,150	200	200
Incinerator-Boiler:				
Number	1	1	1	1
Capacity, lb steam/hour	11,000	5,000	1,250	1,250
Combustion Air Preheater:				
Number	1	1	1	1
Area, Ft^2	105	80	15	15
Control Valves:				
Type	Butterfly	Butterfly	Butterfly	Butterfly
Number	6	6	4	4
Size, inches in diameter	48	48	30 & 24	30 & 24

TABLE 4.4-3
SOLVENT CONTROL SYSTEM FOR TYPICAL AUTO ASSEMBLY PLANT
OPERATING CONDITIONS

Air Source	Paint Spray Booths		Paint Ovens	
Assembly Line	A	B	A	B
Air Temperature, °F	100	100	375	375
Solvent	Toluene	Toluene	Toluene	Toluene
Solvent Concentration, vppm	50	50	300	300
Design Air Flow Rate, scfm	350,000	200,000	10,000	10,000
Normal Air Flow Rate, scfm	320,000	170,000	6,300	8,200
Adsorption				
Bed Depth, inches	12	12	18	18
Carbon Size, mesh	6-8	6-8	6-8	6-8
Air Velocity Across Bed				
Maximum, ft/min	110	110	110	110
Normal, ft/min	101	95	70	90
Carbon Operating Capacity, wt %	7	7	7	7
Solvent Removal Efficiency, %	90	90	90	90
Carbon Life, years	4	4	2	2
Operating Temperature, °F	100	100	100	100
Regeneration Steam				
Steam Rate, lb/lb solvent	10	10	10	10
Steam Pressure, psig	15	15	15	15
Cycle				
Adsorbing, hour	14	14	7.5	7.5
Desorbing, hour	6	6	5.0	5.0
Cooling, hour	1	1	2.5	2.5
Stream Time				
Hours/day	20	20	20	20
Days/week	6	6	6	6
Weeks/year	46	46	46	46

Air Coolers

Air coolers are required in the oven emission control systems to cool the air from 375°F to 100°F prior to entering the adsorbers. Each adsorption system contains 2 water-cooled, floating-head, shell-and-tube air coolers. They are constructed of carbon steel and each has a heat exchange surface of 1500 square feet.

No air coolers are required to pretreat the air from the paint spray booths.

SLA Blowers

A large blower is required for each of the paint spray emission control systems. For the larger system, the blower is sized to handle 350,000 scfm with a head of 17 inches of water. The same head is developed by the blower for the smaller system which is rated at 200,000 scfm.

Each of the smaller oven emission control systems requires a blower sized to handle 10,000 scfm of air and to develop a head of 30 inches of water.

All blowers are designed to operate at 80 percent of rated capacity with an overall efficiency of 65 percent, and all are constructed of carbon steel.

Incinerator-Boiler

Each of the adsorption systems includes an incinerator-boiler in which the regeneration stream, containing steam and desorbed solvent, is burned. The heat produced is used to produce more steam for regeneration. The units are designed to produce two to three times the average amount of required steam. The incinerator-boilers for the spray booth control systems are rated at 11,000 and 5000 pounds of 15 psig steam per hour. Each of the units for the oven control systems is rated at 1250 pounds of steam per hour.

All of the units are designed to use natural gas or fuel oil as an auxiliary fuel for heatup and control purposes.

Combustion Air Preheater

The combustion air required to incinerate the desorbed solvent is preheated before mixing it with the steam-solvent stream to avoid condensing the steam. The source of heat is the incinerator-boiler flue gas.

The exchangers are relatively small and inexpensive. Their size ranges from 105 square feet for the largest system to 15 square feet for the smaller oven emission control system. They are shell and tube exchangers constructed of carbon steel.

Control Valves

All control valves are of the butterfly type. Forty-eight-inch valves are required in the spray booth control systems. Two valves are required on each adsorber, one on the air inlet and one on the air outlet lines. They must be capable of closing with minimal leakage against a pressure of 30 inches of water.

Thirty-inch and twenty-four-inch valves are required on the air inlet and outlet lines, respectively, for the adsorbers in the oven control systems. They are required to close against a head of 50 inches of water. All these valves are constructed of carbon steel.

4.4.3 Plot Plan

Figure 4.4-1 is a rough plot plan showing the equipment arrangement in the solvent emissions control systems for the typical auto assembly plant. In this configuration, the two spray paint booth control systems with the vertical adsorbers are located next to one another. The paint oven control systems, incorporating horizontal adsorbers, are situated at either end of the plot.

A total of about 16,000 square feet (0.4 acre) is taken up by the control system.

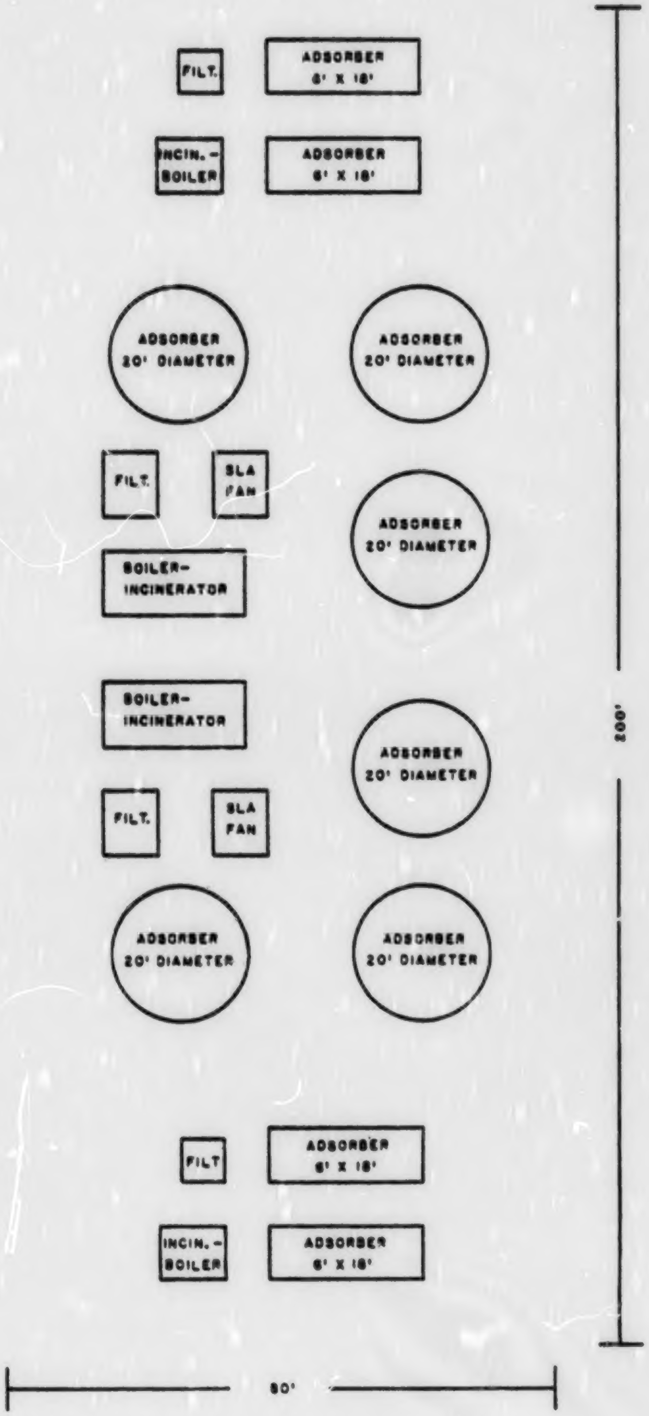
FILT.
ADSORBER 6' X 18'
INCIN.-BOILER
ADSORBER 6' X 18'
ADSORBER 20' DIAMETER
ADSORBER 20' DIAMETER
FILT.
SLA FAN
ADSORBER 20' DIAMETER
BOILER-INCINERATOR
BOILER-INCINERATOR
ADSORBER 20' DIAMETER
FILT.
SLA FAN
ADSORBER 20' DIAMETER
ADSORBER 20' DIAMETER
FILT.
ADSORBER 6' X 18'
INCIN.-BOILER
ADSORBER 6' X 18'
200'
80'

FIGURE 4.4-1

SOLVENT EMISSION CONTROL SYSTEM FOR A TYPICAL AUTO ASSEMBLY PLANT
PLOT PLAN

5.0 PROCESS ECONOMICS

Equipment, utility, and operating costs were determined for emission control systems for the paint booth and oven design cases defined in Sections 4.2 and 4.3, and for a typical auto assembly plant as described in Section 4.4. The costs are enumerated in this section. The sensitivity of the solvent removal cost to variables such as system size, solvent concentration, and air velocity was investigated and is also discussed in this section.

5.1 COST DATA

A number of sources were used in the estimation of equipment costs. Principal among these were the cost data presented by Guthrie (GU-075) for various individual equipment items. Also used were a recent report by McGlamery (MC-136) which gave detailed equipment cost estimates for SO_2 removal processes, Perry (PE-030), Peters and Timmerhaus (PE-065), and estimates by equipment vendors. The equipment costs were brought up to date as of July 1975, using the Chemical Engineering Plant Cost Index.

Utility costs were obtained from several sources including Perry (PE-030), Peters and Timmerhaus (PE-065) and Grandjacques (GR-193).

In some cases, equipment and utility costs represented an average of values obtained from several sources.

5.1.1 Equipment Costs

The purchased costs (f.o.b.) of major equipment items were obtained from the various sources mentioned above. The installed cost of each major piece of equipment was estimated using Guthrie's "bare module" factor (GU-075). This factor represents the average cost incurred when installing specific types of equipment in plants. Included in the installed cost, in addition to the purchase price, are all associated piping, foundation, instrumentation, insulation, field labor, and indirect costs such as freight, taxes, insurance, construction overhead, and contract engineering costs.

Adsorber costs were estimated from Guthrie (GU-075) and included the cost of vessel internals which were priced at one-half the cost of trays for a distillation column of the same size as the adsorbers.

The purchased prices (f.o.b.) of the solvent-laden air blower, incinerator-boiler fan, and drying air fan were based on blower prices from McGlamery (MC-136). Costs were adjusted for size differences using Guthrie's cost size exponent of 0.68 (GU-075).

The costs of the large butterfly control valves were estimated using information from various literature sources (GU-068, LI-134) as well as vendor estimates. Cost data for large (>14") control valves are not readily available, and the values that were finally used represent an average of cost estimates from several sources.

Package boiler prices are presented by Guthrie (GU-075). It was assumed that these costs would suffice for combination vapor incinerater-boilers after adding 10% to the boiler cost to allow for minor modifications. Prices were based on steam capacity.

The combustion air preheaters and air coolers (for cooling the paint oven air) costs were determined from Guthrie (GU-075), and were based on heat exchange surface areas.

The costs of air filters were estimated from information obtained from various sources. Vendor estimates ranged from $10 to $60 for disposable units to treat 2500 cfm. The service time of these units was assumed to be one month. The initial purchase and installation costs represent a combination of values obtained from Perry (PE-030), Guthrie (GU-075), and vendor estimates.

5.1.2 Utility Costs

The utility costs used in this study are listed below:

Natural Gas	$1.00/1000 scf
Electricity	$.034/kwh
Boiler Feedwater	$.50/1000 gal.
Cooling Water	$0.10/1000 gal.
Recoverable heat	$1.00/10^6 Btu

The cost of natural gas was taken from Grandjacques (GR-193) and McGlamery, et al. (MC-136). The price of electricity was also taken from Grandjacques (GR-193), and it is somewhat higher than that found in other sources. It was used, however, because it represents information obtained from an operating solvent recovery plant.

Cooling water and boiler feedwater costs vary widely. Costs in 1967 were $.02-.08/1000 gal for cooling-tower water and $0.15-0.40/1000 gal for boiler feedwater (MO-189, PE-065). Grandjacques (GR-193) used $0.50/1000 gal for process water. In refineries, the cost of boiler feedwater was reported as $0.15/1000 gal (MO-189).

To be conservative, the higher costs for water (adjusted to 1975) were used in developing costs.

Recoverable heat was rated at the same value as that obtained from natural gas. The value of $1.00/MM Btu is approximately equivalent to $1.00/1000 scf for natural gas, since the heating value of natural gas is about 1000 Btu/scf.

5.2 Paint Spray Booth Emission Control Systems

The cost of solvent vapor removal using carbon adsorption systems is highly dependent on a number of variables. One of these is the size or capacity of the system. The capital requirements and operating costs were estimated for spray booth control systems for the design cases described in Section 4.2 of this report. The costs were all determined for battery limits plants installed at ground level in mid-1975. Shown in Table 5.2-1 are the capital and operating costs for Cases I, IIA, IIB, III (Base Case), and IV. The effects of the system size on costs are investigated in these cases.

In Cases I and IIA, horizontal adsorbers are used, while vertical vessels are employed for the larger systems. The capital costs, including a 30% contingency factor and the initial cost of the carbon charge, range from $520M for the 60,000 scfm horizontal system to $4,699M for a system to treat 900,000 scfm (Case IV) using vertical adsorbers. Three major equipment items make up most of the capital costs. By far the largest cost items are the adsorbers, which account for about 50 percent or more of the total installed equipment cost. The relative costs of the solvent-laden air blowers and the large control valves vary according to the size and configuration of the system. The cost of the SLA blowers ranges from $39.5M for Case I to $302M for Case IV, and rises with increasing system capacity. The cost of

TABLE 5.2-1
SOLVENT EMISSION CONTROL BY CARBON ADSORPTION/INCINERATION
SPRAY BOOTH SYSTEMS: CAPITAL AND OPERATING COSTS (BATTERY LIMITS PLANT)

	CASE				
CASE	I	IIA	IIB	III (Base Case)	IV
Solvent	Toluene	Toluene	Toluene	Toluene	Toluene
Solvent concentration, ppm	50	50	50	50	50
Air Flow Rate, scfm	60,000	250,000	250,000	450,000	900,000
Air Velocity Through Bed, ft/min	110	110	110	110	110
Capital Cost (Installed, 1975), $					
Adsorbers	233,700	779,000	1,021,200	1,599,000	2,666,000
SLA Blowers	39,500	102,000	102,000	151,000	302,000
Other Blowers	4,000	7,000	7,500	9,500	9,500
Boiler/Incinerator	12,500	18,000	18,000	33,000	52,000
Control Valves	74,400	248,000	120,000	120,000	240,000
Air Preheater	6,000	11,000	19,000	24,000	24,000
Filters	10,500	25,000	25,000	50,000	90,000
	380,600	1,190,000	1,312,500	1,986,500	3,384,000
Contingency (30%)	114,200	357,000	393,800	597,000	1,015,000
	494,800	1,547,000	1,706,300	2,583,500	4,399,000
Carbon @ $1.00/lb	25,200	84,000	103,000	180,000	300,000
Total Capital, $	520,000	1,631,000	1,809,300	2,763,500	4,699,000
Operating Cost $/Year					
Utilities: Fuel @ $1.00/ 1000 scf	400	1,000	2,600	4,900	5,700
Electricity @ $.034/kwh	39,400	159,800	159,800	283,900	561,000
Boiler Feedwater @ $0.50/100 gal	200	500	500	1,000	2,200
Recoverable Heat @ $1.00/MM Btu	(900)	(3,400)	(7,100)	(6,600)	(8,800)
Operating Labor @ $10.00/ Man-hr	11,000	16,500	16,500	27,500	27,500
Maintenance @ 4% of Capital Cost	21,000	65,000	72,000	111,000	188,000
Carbon Replacement (4-year life)	6,300	21,000	25,800	45,000	75,000
Capital Charge @ 12% interest	96,200	301,700	315,700	478,600	813,800
Total Operating Cost	173,600	562,100	585,800	945,300	1,664,400
Solvent Removed, lb/year	216,800	901,000	901,000	1,630,000	3,260,000
Solvent Removal Cost					
$/lb	0.80	0.62	0.65	0.58	0.51
$/scfm-year	2.89	2.25	2.35	2.10	1.85
Capital Cost $/scfm	8.67	6.52	7.24	6.15	5.22

the control valves is dependent on the configuration of the system as well as the size. For example, the cost of the valves for Case IIA (250,000 scfm) is $248M, while in Case III (450,000 scfm) the value is only $120M. This is due to the use of 10 horizontal adsorbers, requiring 20 valves for Case IIA, as opposed to 3 large vertical adsorbers and 6 valves for Case III.

The effect of the system size on the capital cost is presented graphically in Figure 5.2-1. In terms of system capacity, the capital cost ranges from $5.22 to $8.67/scfm. The cost decreases as the size of the system increases.

The annual operating costs range from $174M for the 60,000 scfm size system (Case I) to $1,554M for the 900,000 scfm (Case IV). The operating labor requirements range from 0.1 to 0.5 man/shift for Cases I and IV, respectively. Maintenance was set at 4% of the total capital cost and includes monthly replacement of the filter medium. The capital cost (excluding the cost of the carbon) is amortized at an annual interest rate of 12 percent over a ten-year period.

As might be expected, the capital charge represents the highest single operating cost. The next highest operating cost is electricity, which is used almost entirely to drive the SLA blowers. Thus, it can be seen that any increase in required carbon bed depth and associated pressure drop through the system will be very costly in terms of operating costs. If the bed depth is doubled from 12 inches to 24 inches, the cost of electricity to power the SLA blowers would probably exceed the capital charges for the larger systems.

The solvent removal costs vary from $0.80 to $0.51 per pound of solvent removed, with the cost declining as the size of

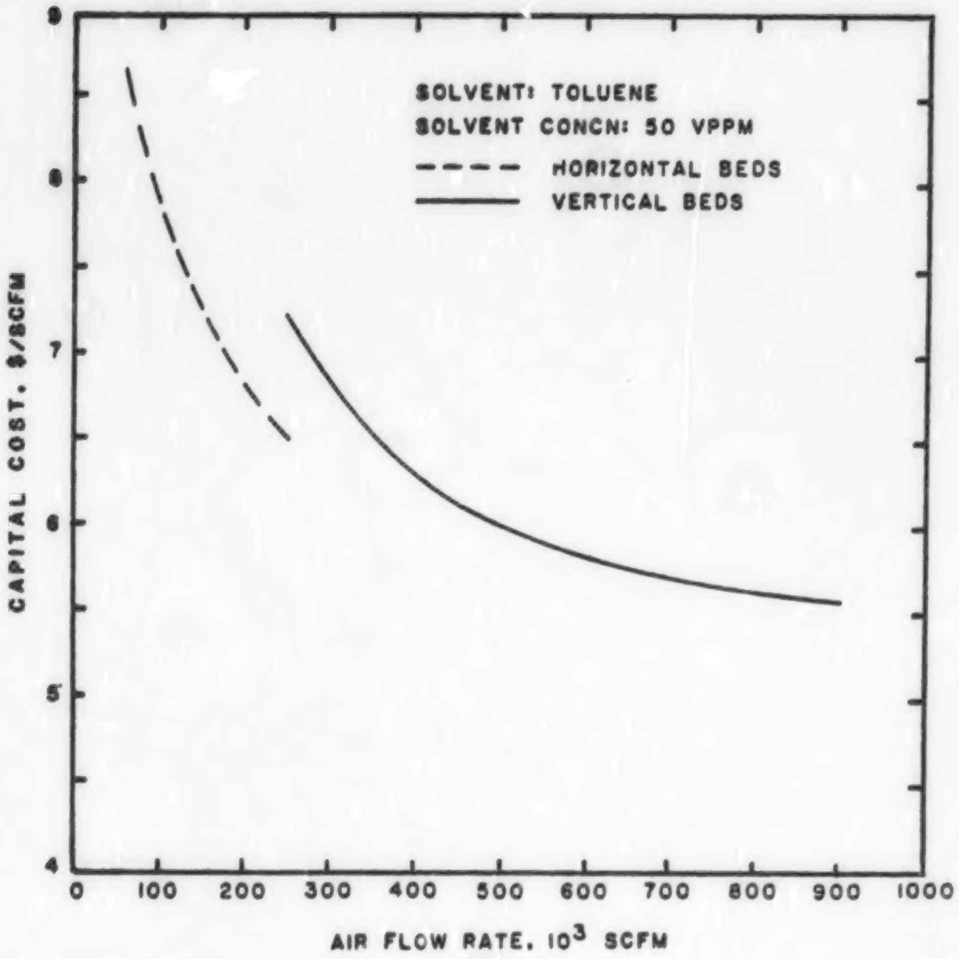

FIGURE 5.2-1

CARBON ADSORPTION SYSTEM FOR SPRAY BOOTH SOLVENT EMISSION CONTROL

CAPITAL COST: EFFECT OF AIR RATE

the system becomes larger. In terms of system capacity, the removal costs range from $2.89 to $1.85 per year per scfm. The solvent removal costs as a function of system size are shown in Figures 5.2-2 and 5.2-3.

5.3 Paint Oven Emission Control Systems

The solvent removal costs were determined as a function of the system size or capacity for paint oven emissions. The capital and operating costs are presented in Table 5.3-1 for four cases (Cases IX-XII) with the size of the systems ranging from 10,000 scfm to 250,000 scfm. All costs were calculated for battery limits plants installed at ground level in 1975.

In comparing the capital costs associated with oven emission controls to those estimated for spray booth systems, it is immediately apparent that oven control systems are much costlier. The capital costs range from $383M to $3,309M for systems processing solvent-laden air volumes of 10,000 to 250,000 scfm, respectively. By comparison, a capital cost of $1,531M is required to treat 250,000 scfm of air from spray booths (Case IIA). There are several reasons for the higher costs. It requires more equipment to process air from paint ovens. The air must be cooled and the air coolers are quite large and very expensive. The solvent concentration in the oven air is 300 vppm as compared to 50 vppm used in developing costs for spray booth control systems. The higher concentration results in the need for larger boiler-incinerators, deeper beds, and larger SLA blowers. The capital cost is shown as a function of the system capacity in Figure 5.3-1.

The operating costs are also much higher for oven control systems. Part of the greater cost is due, of course, to the higher capital charge. Another very large operating cost, however, is the cooling water required to cool the incoming air. This cost is

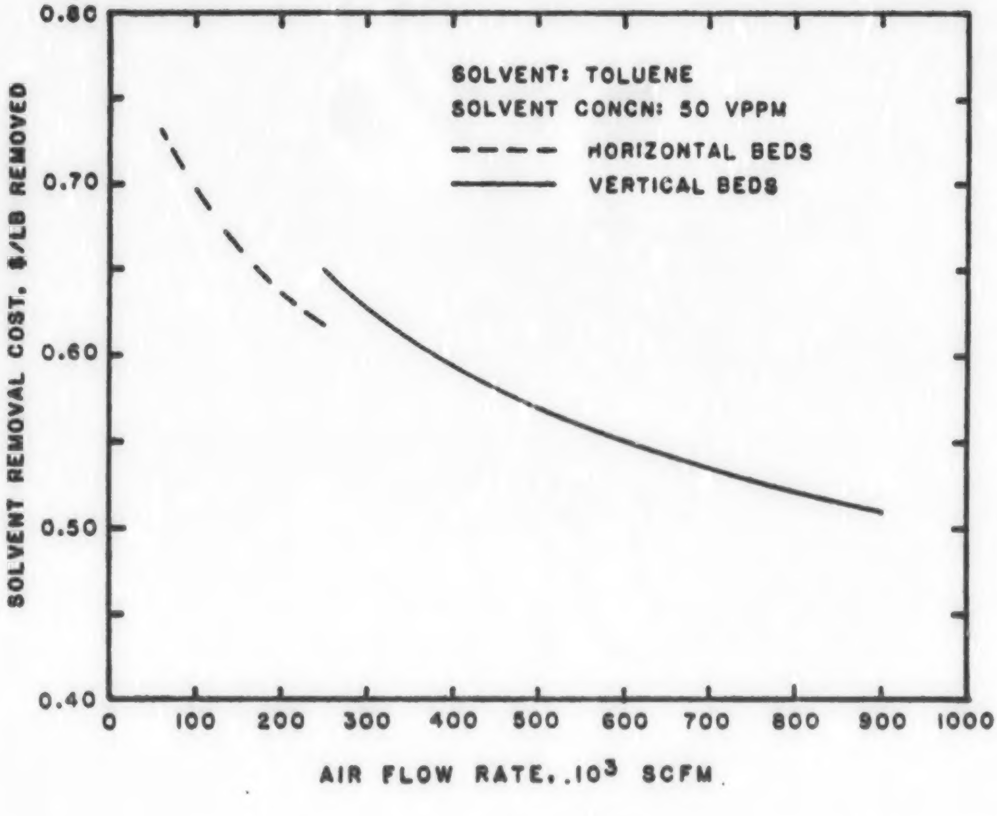

FIGURE 5.2-2
CARBON ADSORPTION SYSTEM FOR SPRAY BOOTH SOLVENT EMISSION CONTROL
SOLVENT REMOVAL COST: EFFECT OF AIR FLOW RATE

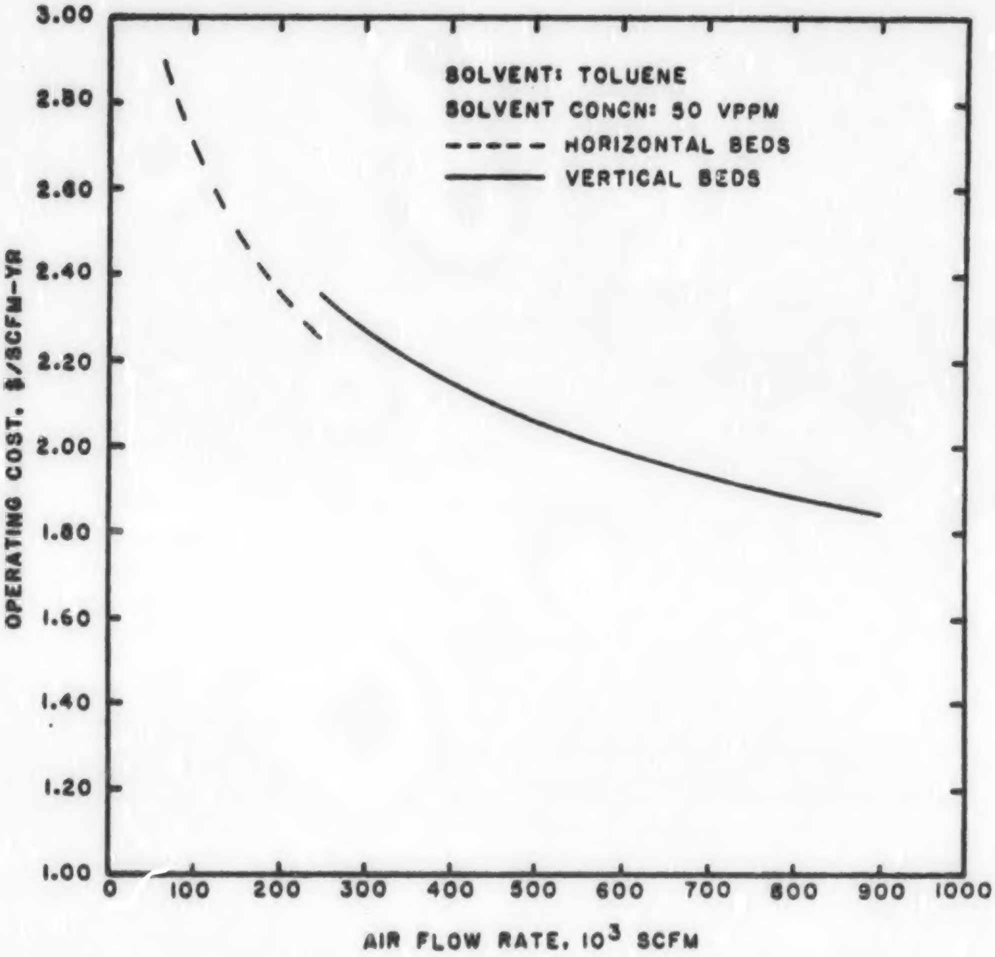

FIGURE 5.2-3

CARBON ADSORPTION SYSTEM FOR SPRAY BOOTH SOLVENT EMISSION CONTROL

OPERATING COSTS: EFFECT OF AIR FLOW RATE

TABLE 5.3-1

CARBON ADSORPTION SYSTEMS: CAPITAL AND OPERATING COSTS (BATTERY LIMITS PLANT)

PAINT BAKE OVENS

CASE	IX	X	XI	XII
Solvent	Toluene	Toluene	Toluene	Toluene
Solvent Concentration, vppm	300	300	300	300
Air Flow Rate, scfm	10,000	20,000	50,000	250,000
Air Velocity Through Bed, Ft/min	110	110	110	110
Capital Cost, $				
Adsorbers	70,600	107,000	181,800	855,900
SLA Blower	25,500	40,900	74,800	284,000
Air Coolers	146,600	190,600	317,800	828,000
Boiler/Incinerator	12,000	19,400	14,300	111,900
Control Valves	21,000	45,000	68,000	270,000
Air Preheater	2,900	4,500	9,300	20,100
Filters	6,100	9,200	16,000	41,900
Other Blowers	2,900	4,600	7,100	17,000
	287,600	421,200	689,100	2,428,800
Contingency, 30%	86,300	126,400	206,700	728,600
	373,900	547,600	895,800	3,157,400
Carbon @ $1.00/lb	9,000	16,800	31,500	151,200
Total Capital	382,900	564,400	927,300	3,308,600
Operating Cost, $/year				
Utilities: Fuel @ $1.00/ 1000 scf	900	1,600	1,900	24,800
Electricity @ $.034/kwh	11,200	22,400	54,700	285,600
Boiler Feedwater @ $0.50/1000 gal	200	300	800	3,500
Cooling water @ $0.10/1000 gal	13,900	27,800	69,300	348,200
Recoverable heat @ $1.00/MM Btu	(1,300)	(2,600)	(4,400	(33,800)
Operating Labor @ $10.00/man hour	5,500	5,500	11,000	27,500
Maintenance @ 5% of capital	19,200	28,200	46,400	165,400
Carbon Replacement (2-year life)	4,500	8,400	15,800	75,600
Capital Charge @ 12% interest	69,200	101,300	165,700	584,100
Total Operating Cost	123,300	192,900	361,200	1,480,900
Solvent Removed, lb/year	179,000	432,300	1,080,000	5,420,000
Solvent Removal Cost				
$/lb	0.69	0.45	0.33	0.27
$/scfm-year	12.33	9.65	7.22	5.92
Capital Cost, $/scfm	38.29	28.22	18.55	13.23

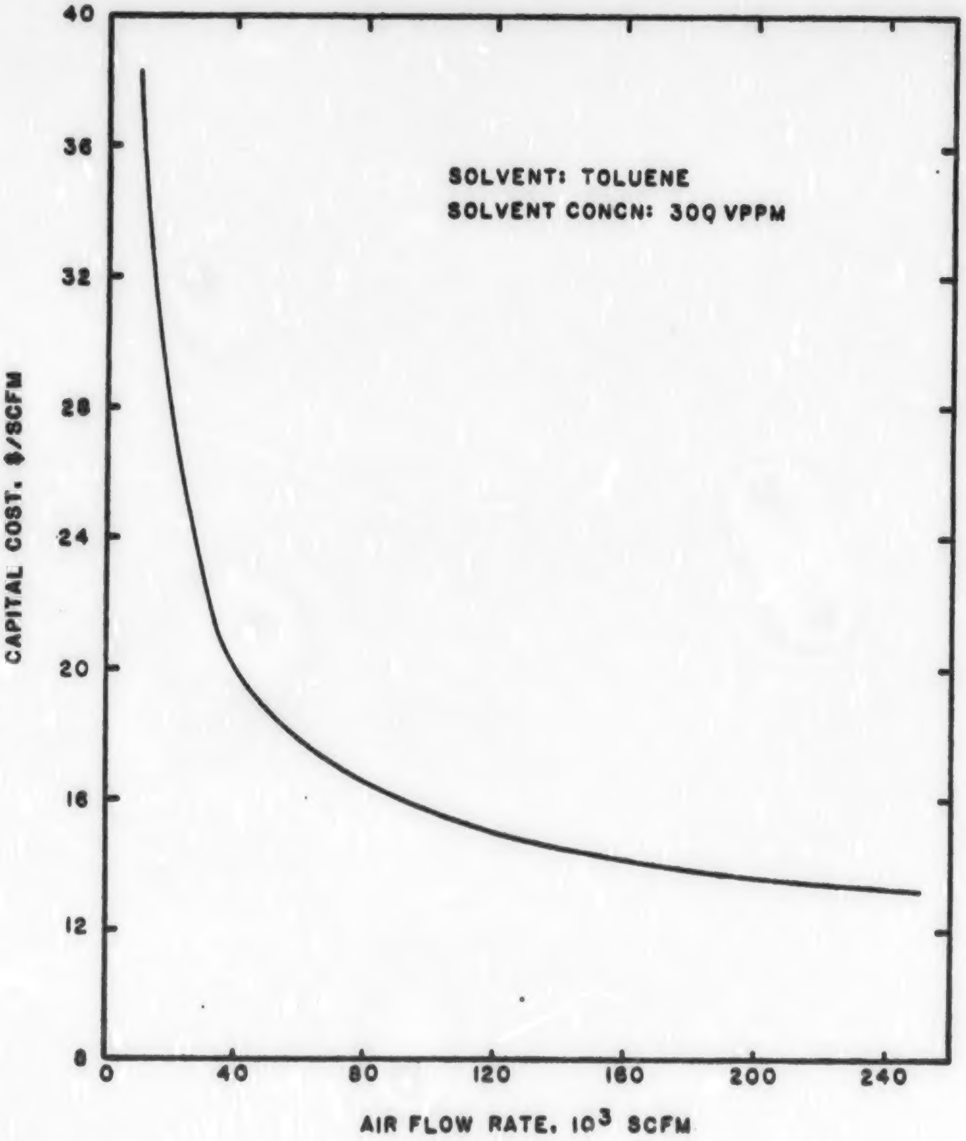

FIGURE 5.3-1
CARBON ADSORPTION SYSTEM FOR PAINT OVEN SOLVENT EMISSION CONTROL
CAPITAL COSTS: EFFECT OF AIR RATE

directly proportional to the amount of air treated by the system. The electrical power is used almost exclusively to drive the SLA blowers, and the cost of electricity, like cooling water, increases directly with the volume of air treated.

Maintenance costs are higher than those for the spray booths because, in addition to replacing filter mediums, the air coolers may have to be cleaned often to remove deposits of high boiling compounds emitted from the pain ovens. If these materials are not present in the oven air, maintenance costs would be lowered significantly, and the purchase of only one air cooler would be required.

The cost of removing solvent vapor from paint oven air is presented graphically as a function of the capacity in Figures 5.3-2 and 5.3-3. The cost ranges from $0.69 to $0.27 per pound of solvent removed for systems processing 10,000 to 250,000 scfm of air, respectively. In terms of capacity, the cost is $12.33 per year per scfm for the system handling 10,000 scfm. This cost drops to $5.92 per year per scfm for Case XII (250,000).

5.4 Control System for a Typical Auto Assembly Plant

The costs of installing and operating a solvent control system for the typical auto assembly plant as defined in Section 4.4 were estimated. The costs, summarized in Table 5.4-1, are for a battery limits plant located at ground level and completed in mid-1975. The costs do not include any off-site facilities such as air collection ducts, cooling tower, power station, etc. The plant is of sufficient size to reduce the solvent emissions to 3000 pounds per day for each spray booth and by 85% for each oven.

The total capital cost for the control system is $4,504M or $7.90 per scfm. The costliest capital items are the adsorbers, which account for over 50 percent of the overall cost. The SLA

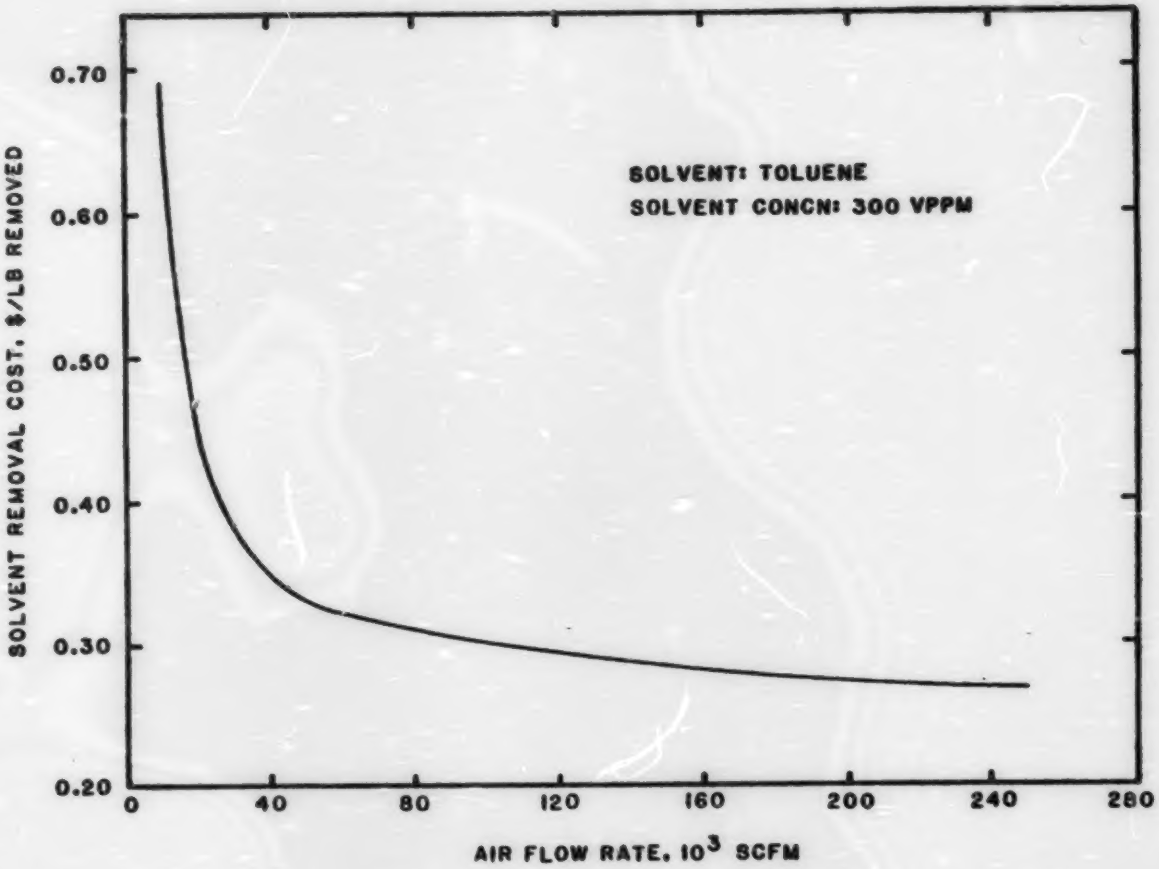

FIGURE 5.3-2

CARBON ADSORPTION SYSTEM FOR PAINT OVEN SOLVENT EMISSION CONTROL
SOLVENT REMOVAL COSTS: EFFECT OF AIR FLOW RATE

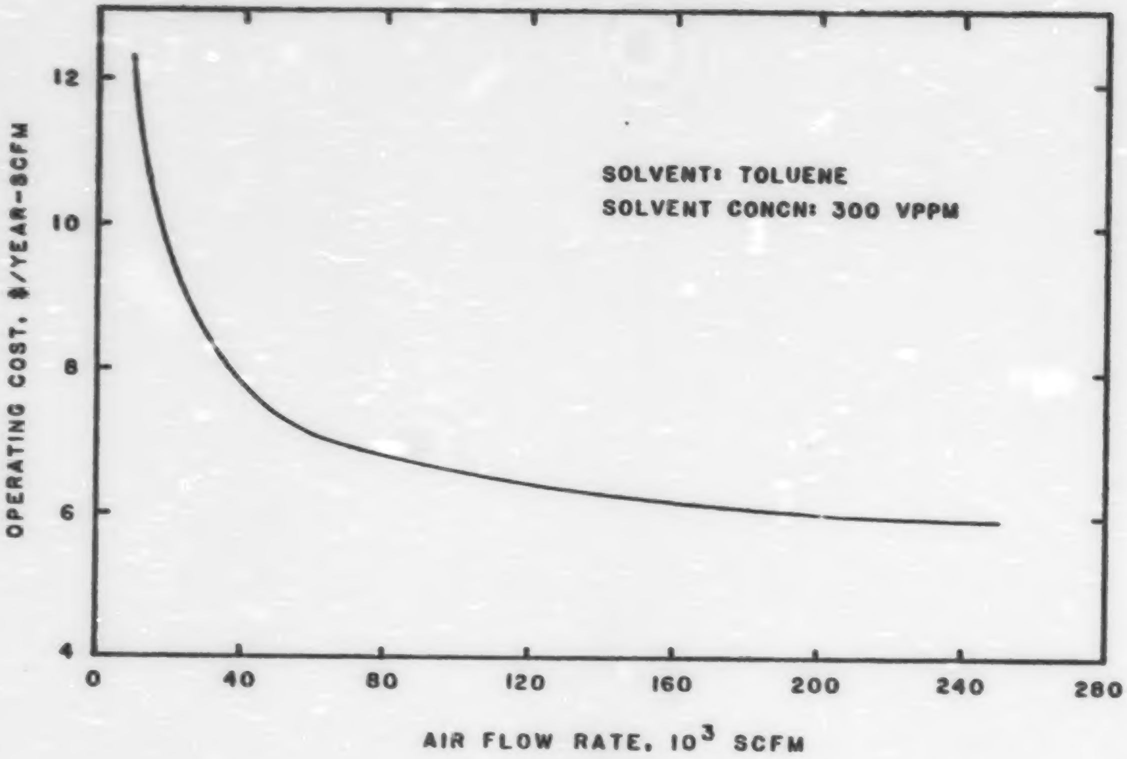

FIGURE 5.3-3

CARBON ADSORPTION SYSTEM FOR PAINT OVEN SOLVENT EMISSION CONTROL
OPERATING COSTS: EFFECT OF AIR FLOW RATE

TABLE 5.4-1
COST OF SOLVENT EMISSION CONTROL SYSTEM FOR TYPICAL AUTO ASSEMBLY PLANT
(BATTERY LIMITS PLANT)

System: Type	Paint Spray Booths		Paint Ovens		
Air Capacity, scfm	350,000	200,000	10,000	10,000	
Assembly Line	A	B	A	B	
					Totals
Capital Cost, $					
Adsorbers	1,250,000	895,000	70,600	70,600	2,286,200
BLA Blowers	130,000	91,000	25,500	25,500	272,000
Other Blowers	7,500	6,400	2,900	2,900	19,700
Boiler-Incinerator	22,800	13,000	12,000	12,000	59,800
Control Valves	120,000	120,000	21,000	21,000	282,000
Air Coolers	-	-	121,400	121,400	242,800
Air Preheater	23,600	19,800	2,900	2,900	49,200
Filters	30,600	22,000	6,100	6,100	64,800
	1,584,500	1,167,200	262,400	262,400	3,276,500
Contingency @ 30%	475,400	350,200	78,700	78,700	983,000
	2,059,900	1,517,400	341,100	341,100	4,259,500
Initial Carbon Charge, $	144,000	82,500	9,000	9,000	244,500
	2,203,900	1,599,900	350,100	350,100	$4,504,000
Operating Cost, $/Year					
Utilities: Gas	3,600	2,100	600	800	7,100
Electricity	221,000	125,800	7,100	9,200	363,100
Boiler Feedwater	700	400	100	100	900
Cooling Water	-	-	8,800	9,200	18,000
Energy Credit	(9,900)	(5,700)	(800)	(1,200)	(17,600)
Operating Labor	22,000	22,000	5,500	5,500	55,000
Maintenance	88,200	63,600	17,500	17,500	186,800
Carbon Replacement	36,000	20,600	4,500	4,500	65,600
Capital Charge @ 12% interest	381,100	280,700	64,800	64,800	791,400
	742,700	509,300	108,200	110,500	$1,470,300
Total Solvent Removed, lb/year	1,159,200	607,400	137,900	179,300	2,083,800
Solvent Removal Cost,					
$/lb	0.64	0.84	0.78	0.62	0.71
$/scfm-year	2.12	2.55	10.82	11.05	
Capital Cost, $/scfm	6.30	8.00	35.01	35.01	7.90

blowers, control valves, and air coolers are all approximately equal in cost.

As might be expected, the capital charge, amortized over a ten-year period at 12% annual interest, is the largest single component of the operating cost. The utilities requirements are listed in Table 5.4-2. Of particular interest is the cost of electricity, which at $363M per year, makes up 25% of the total annual operating cost. The cost of natural gas at $7.1M per year is very small compared to that of the electricity. When the credit for recovered heat is compared to the cost of the natural gas, it can be seen that, for this plant, incineration of the solvent provides more heat than is required for steam generation.

Maintenance cost is relatively high due to the required periodic replacement of the filter medium and cleaning of the air coolers to remove condensed material.

The total solvent removed by the control systems amounts to 2,084,000 pounds per year. The removal cost is $0.71 per pound or $1420 per ton of solvent removed. In Table 5.4-3 the cost effectiveness of this system is compared to other methods of reducing hydrocarbon emissions. It is more expensive than balance systems for refueling emissions at service stations, but less costly than motor vehicle emission control methods.

It should be emphasized that no significant attempt was made to optimize the equipment or plant design in order to minimize costs. When data from individual auto assembly plant paint operations become available, such optimization might significantly reduce some of the costs associated with carbon adsorption/incineration control systems. For example, the power requirements

TABLE 5.4-2
SOLVENT EMISSIONS CONTROL SYSTEM FOR HYPOTHETICAL AUTO ASSEMBLY PLANT UTILITIES REQUIREMENTS

Natural Gas	7.1×10^6 scf/year
Electricity	10.7×10^6 kwh/year
Boiler Feedwater	2.8×10^6 gal/year
Cooling Water	180×10^6 gal/year
Energy Credit	17.6×10^9 Btu/year

TABLE 5.4-3

COST EFFECTIVENESS OF METHODS AVAILABLE FOR REDUCING HYDOCARBON EMISSIONS

	$/Ton Controlled
Degreasing Controls	1
Dry Cleaning Controls	29
Painting Substitutions	116
Jet Engine Modification	177
Balance System for Refueling Emissions at Service Stations	634
Jet Aircraft Towing	894
Solvent Vapor Removal from Air by Carbon Adsorption**	1,420
Piston-Aircraft Afterburner	3,610
LDMV* Minor Exhaust Retrofit	3,010
LDMV* Evaporative Controls	3,250
LDMV* Catalytic Converter	3,700
LDMV* State Inspection/Maintenance	5,830
Maximum LDMV* Maintenance	16,300
Modest Bus Improvement	13,300
Modest Mileage Surcharge	13,300
Heavy Mileage Surcharge	18,000
Major Bus Improvements	31,000

* LDMV - Light Duty Motor Vehicles

** Cost for typical auto assembly plant as defined in this study. Costs are based on battery limits plant only.

Source: GO-091, CA-294

of the SLA blowers can be reduced through the use of a shallower bed and/or lower air velocity. The reduction in power requirements can only be accomplished, however, at the expense of additional capital. A carbon bed shallower than 12 inches (if practical) will require more frequent regeneration and, therefore, larger regeneration equipment. If the air velocity is reduced, more bed area and larger adsorbers are needed.

As another example, the cost of cooling oven air might be reduced by using air-cooled instead of water-cooled exchangers. The additional cost of air-cooled exchangers followed by water-cooled trim coolers might be outweighed by the savings in cooling water costs, particularly if new cooling tower capacity is necessary. Depending on individual plant requirements, the cost of off-site equipment such as air collection ducts, cooling tower, electrical substation, etc., could add substantially to the solvent removal costs. For example, the installed cost of an 8' by 8' duct is about $100 per linear foot (GU-079). The cost of off-site equipment could be as high or higher than the cost of the battery limits plant.

The amount of air to be treated could be minimized by evaluating the individual air streams and treating only those which have higher solvent concentrations.

5.5 Sensitivity Study

A wide-ranging study of the sensitivity of the solvent removal costs to the many variables is beyond the scope of this work. It was possible, however, to do a brief investigation of the effects of air velocity and solvent concentration on the capital and operating costs. This was done for Cases V through VIII, which were then compared to the Base Case III. The cost breakdown for these cases is shown in Table 5.5-1.

TABLE 5.5-1

PAINT SPRAY BOOTH CONTROL SYSTEM CAPITAL AND OPERATING COSTS (BATTERY LIMITS PLANT)

EFFECT OF AIR VELOCITY AND SOLVENT CONCENTRATION

CASE	III (Base Case)	V	VI	VII	VIII
Solvent	Toluene	Toluene	Toluene	Toluene	Toluene
Solvent Concentration, ppm	50	50	50	150	300
Air Flow Rate, scfm	450,000	450,000	450,000	450,000	450,000
Air Velocity Through Bed, ft/min	110	80	50	110	110
Capital Cost (Installed, 1975), $					
Adsorbers	1,599,000	2,132,000	3,198,000	1,599,000	1,599,000
SLA Blowers	151,000	130,000	102,400	151,000	183,000
Other Blower	9,500	13,000	13,000	13,000	13,800
Control Valves	120,000	160,000	240,000	120,000	120,000
Air Preheater	24,000	24,000	24,000	16,000	25,000
Filters	50,000	50,000	50,000	50,000	50,000
	1,986,500	2,542,000	3,660,400	2,037,400	2,094,900
Contingency (30%)	597,000	763,000	1,098,100	611,200	628 500
	2,583,500	3,305,000	4,748,500	2,648,600	2,723,400
Carbon @ $1.00/lb	180,000	237,400	356,800	180,000	258,000
Total Capital,	2,763,500	3,642,400	5,105,300	2,828,600	2,981,400
Operating Cost, $/Year					
Utilities: Fuel @ $1.00/1000 scf	4,900	4,900	4,900	18,000	36,100
Electricity @ $.034/kwh	283,900	224,400	137,400	283,900	368,200
Boiler Feedwater @ $0.50/1000 gal	1,000	1,000	1,000	3,200	6,500
Recoverable Heat @ $1.00/MM Btu	(6,600)	(6,600)	(6,600)	(33,500)	(61,600)
Operating Labor @ $10.00/Man-Hour	27,500	27,500	27,500	27,500	27,500
Maintenance @ 4% of Capital Cost	111,000	146,000	204,000	113,000	119,000
Carbon Replacement (4-Year Life)	45,000	59,400	89,200	45,000	64,500
Capital Charge @ 12% interest	478,600	611,400	878,500	490,000	503,800
Total Operating Cost	945,300	1,068,000	1,355,900	947,100	1,064,000
Solvent Removed, lb/year	1,630,000	1,630,000	1,630,000	4,891,000	9,757,000
Solvent Removal Cost,					
$/lb	0.58	0.65	0.83	0.19	0.11
$/scfm-year	2.10	2.37	3.01	2.10	2.36
Capital Cost, $/scfm	6.15	8.09	11.35	6.29	6.62

The effect on costs of reducing air velocity through the carbon bed in a spray booth control system is presented graphically in Figures 5.5-1 and 5.5-2. Except for the air velocity, the conditions are the same as those of Case III (Base Case) which were described in Section 4.2. As the allowable velocity decreases, the required bed face area increases, thus increasing the size of the adsorbers, which are the costliest equipment items in the system. As shown in Figure 5.5-1, the capital cost rises from $6.15 per scfm at an air velocity of 110 fpm to $11.35 per scfm at an air velocity of 50 fpm. The effect of the air velocity on the solvent removal cost can be seen in Figure 5.5-2. As the velocity is decreased from 110 to 50 fpm, the cost of removing solvent from the air rises from $0.58 to $0.83 per pound of solvent removed. The increase in operating cost due to the higher capital charge is partially offset by the decrease in the power consumption by the SLA blower. For example, the cost of electricity drops from $284M to $159M per year as the velocity decreases from 110 to 50 fpm.

The effect of increased solvent concentration on capital costs is not large, at least in the range of 50 to 300 vppm concentration. This is evident from Figure 5.5-3. The capital cost is $5.15 per scfm at a toluene concentration of 50 vppm and rises to only $6.62 per scfm at 300 vppm, an increase of less than 8 percent. The cost of the adsorbers is the same for all solvent concentrations within the range of the study. The increase in capital requirements at the higher concentrations comes from the larger SLA blowers required to overcome the increased resistance across the deeper bed.

The operating cost rises from $945M to $1,064M per year as the solvent concentration increases from 50 to 300 ppm. More fuel is needed at the higher concentrations for control purposes and bed heatup due to the shorter regeneration time. However,

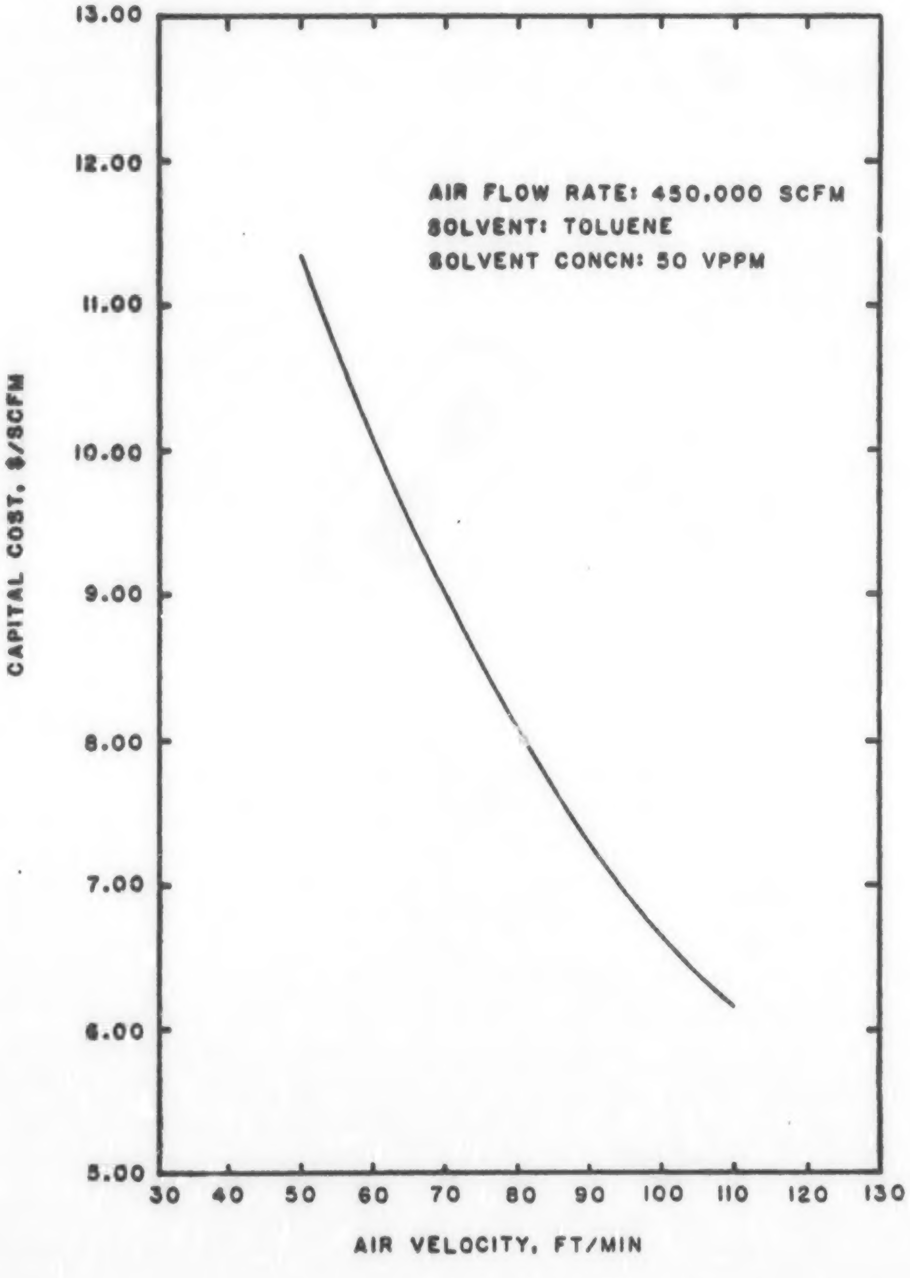

FIGURE 5.5-1

CARBON ADSORPTION SYSTEM FOR SPRAY BOOTH SOLVENT EMISSION CONTROL CAPITAL COSTS: EFFECT OF AIR VELOCITY

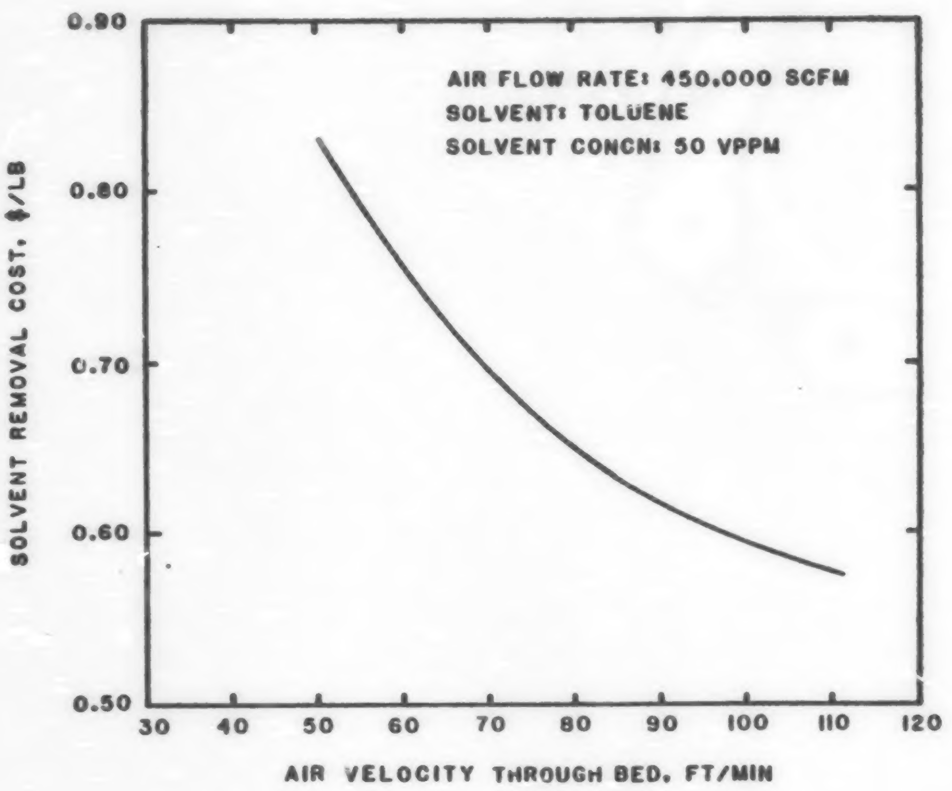

FIGURE 5.5-2

CARBON ADSORPTION SYSTEM FOR SPRAY BOOTH SOLVENT EMISSION CONTROL

SOLVENT REMOVAL COST: EFFECT OF AIR VELOCITY

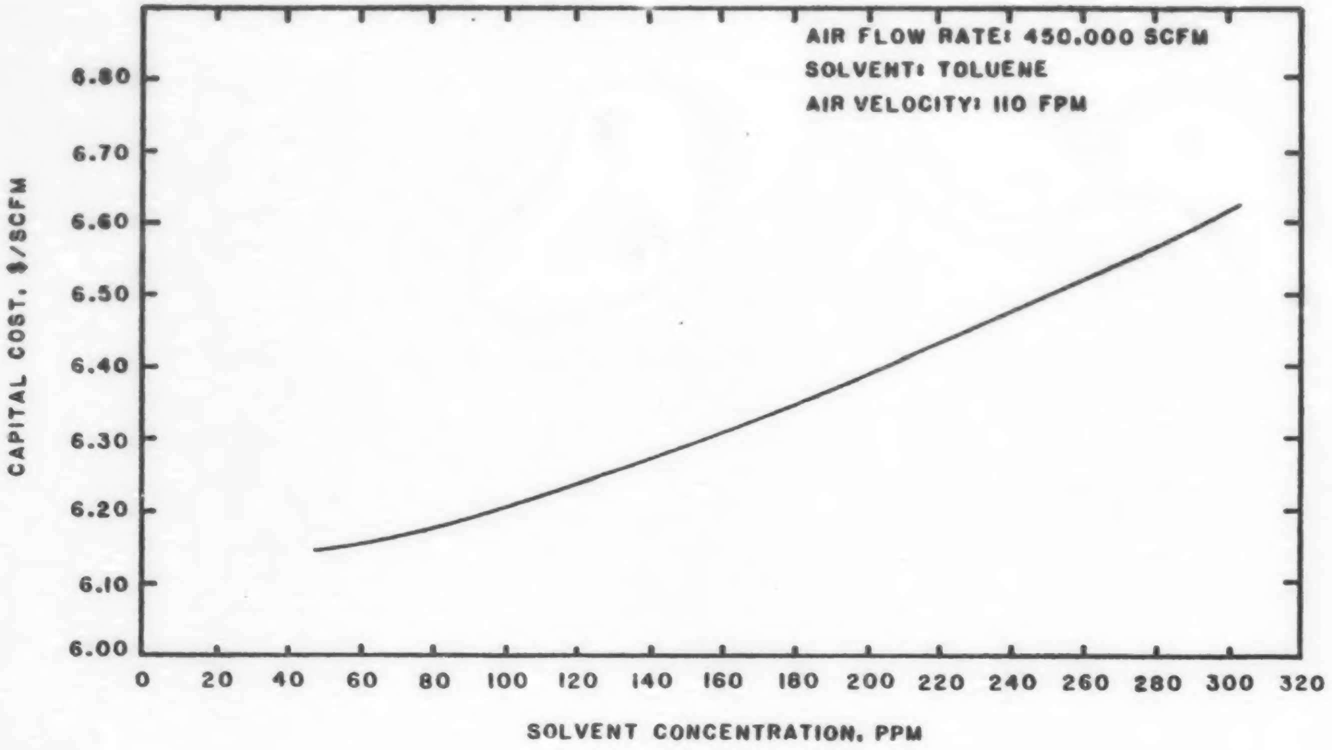

FIGURE 5.5-3

CARBON ADSORPTION SYSTEM FOR SPRAY BOOTH SOLVENT EMISSION CONTROL

CAPITAL COSTS: EFFECT OF SOLVENT CONCENTRATION all this heat, and more, is recovered. The power requirements are somewhat higher at the 300 vppm concentration. This is due to the need for a larger blower as discussed in the preceding paragraph. As illustrated in Figure 5.5-4, the solvent removal cost declines from \$0.58 to \$0.11 per pound as the solvent concentration increases. Although the operating cost rises somewhat, the amount of solvent removed increases from 1,630M to 9,757M pounds per year, resulting in decline in the removal cost on a per-pound basis.

Certainly, as the solvent concentration is increased beyond 300 vppm the operating cost will continue to rise. When the concentration gets high enough, more adsorbers will be required and at this point the capital cost will rise more significantly.

The solvent concentration in the regeneration stream from the adsorbers will vary during the regeneration cycle. If the variation is too great to permit efficient operation of the incinerator for direct vapor incineration, the solvent/steam mixture can be condensed. The liquid solvent and water can then be incinerated at a steady rate. Additional operating costs would be incurred primarily from the increased use of cooling water and incinerator fuel. For example, the total operating costs for Case III (Table 5.5-1) would be increased by 10-15% over those for the noncondensing mode of operation.

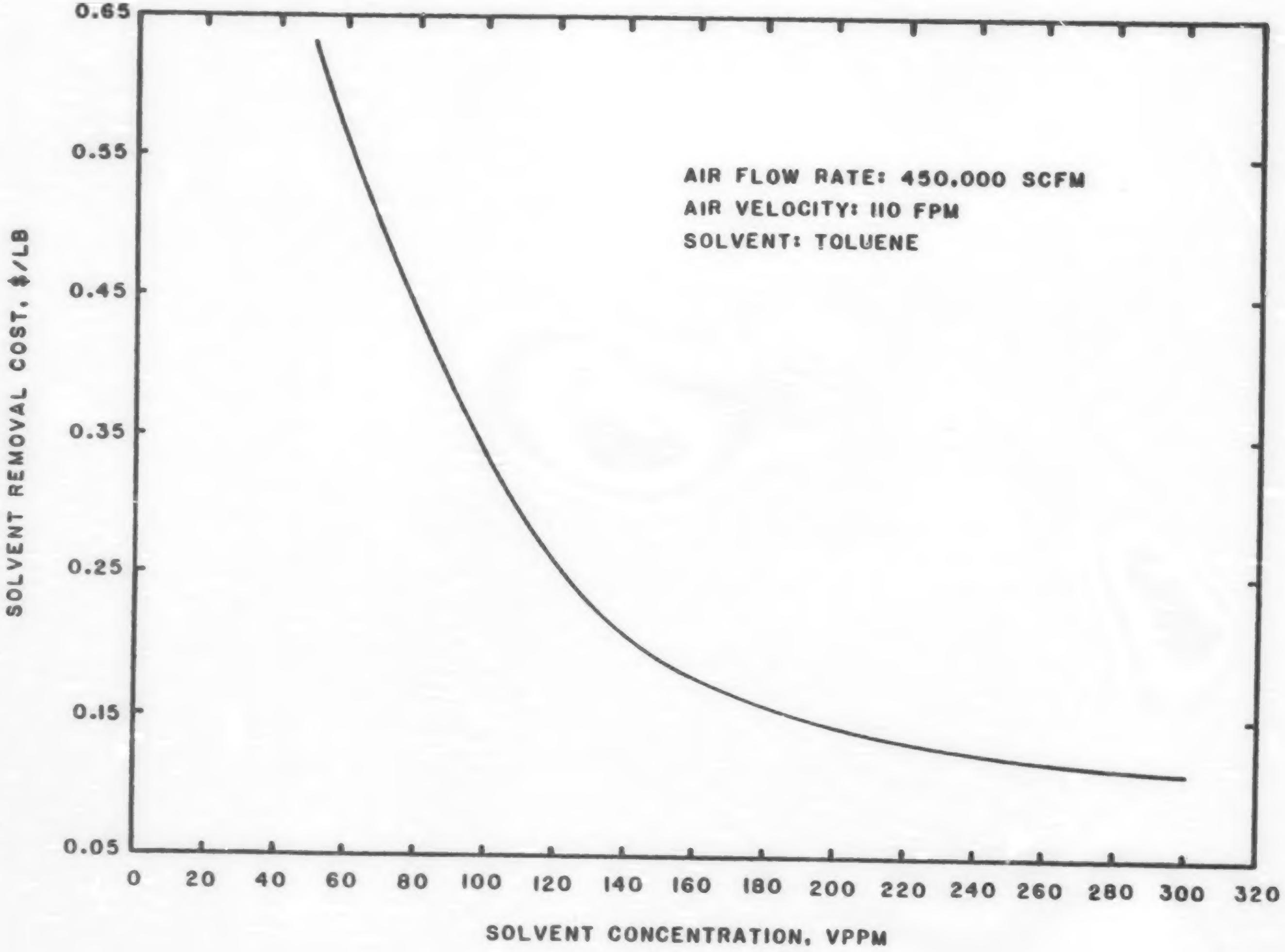

FIGURE 5.5-4

CARBON ADSORPTION SYSTEM FOR SPRAY BOOTH SOLVENT EMISSION CONTROL

SOLVENT REMOVAL COSTS: EFFECT OF SOLVENT CONCENTRATION

6.0 ENERGY CONSIDERATIONS

The carbon adsorption/incineration system effectively concentrates the solvent for a more efficient incineration. Some fuel will be required, however, to start the regeneration and to provide some control of the steam rate during the regeneration. The fuel requirements, availability, and the subsequent recovery of the combustion/incineration heat are discussed in the following sections.

6.1 Fuel Requirements

The fuel requirements for the adsorption/incineration system are quite small within the range of process and operating conditions selected as bases for the various design cases in this report. The control system for the typical auto assembly plant, for example, requires only 7.1 x 10^9 Btu per year in supplemental heat. This is equivalent to about 7.1 x 10^6 scf of natural gas or about 50,000 gallons of fuel oil. By comparison, about 32 x 10^9 Btu per year are required to heat 20,000 scfm of air from 75°F up to 375°F as in a bake oven operation.

Actually, the heat produced from burning the regeneration stream of toluene and steam is more than sufficient to manufacture the steam required in the regeneration. The supplemental fuel is necessary to initially heat the adsorber and carbon bed from the adsorbing temperature of 100°F or less up to the regeneration temperature of 220°F. In addition, some supplemental fuel will undoubtedly be necessary in order to control the regeneration steam rate, since the output of solvent vapor from the adsorber will not be steady during the regeneration.

6.2 Fuel Availability

The availability of fuels is dependent on both the type of fuel required and the location of the plant. Natural gas is in short supply for industrial use in many areas. The supply is usually tightest in the northern and eastern sectors of the U.S.

If natural gas is to be used as the supplemental fuel source in carbon adsorption/incineration systems it should be available to the auto assemply plant under supply conditions similar to those already in existence at the plant. For example, if the gas being used at the plant is delivered on an interruptible basis, the bake ovens will not be operating during periods of interrupted supply, the paint assembly line will be shut down, and the solvent removal system will not be needed.

In some areas, however, it may be impossible to obtain natural gas for new facilities, or it may be available under conditions which would make its use impractical. In these cases it would be advisable to consider other fuels such as fuel oil. As discussed in Section 6.1, about 50,000 gal/year of fuel oil would be needed to supply the supplemental fuel requirements of the adsorption systems for the typical auto assembly plant. This would require a minimal amount of tankage and additional equipment.

6.3 Energy Recovery

At a steam/solvent ratio of 15-20 pounds of steam per pound of adsorbed solvent, enough solvent is present (at average rate of solvent desorption during regeneration) in the regeneration vapor stream to sustain combusion, i.e., to maintain an incinerator temperature of 1400-1500°F. At these steam/solvent ratios, more heat than needed to produce regeneration steam is provided by the combustion of the solvent. In the design cases of this study, additional heat is supplied from the supplemental fuel used to initially heat the bed and for control purposes. Even after producing enough steam for regeneration, a considerable amount of energy is still available in the form of hot flue gas. The flue gas leaves the incinerator-boiler at a temperature of about 750-800°F. The flue gas is used to preheat the combustion air from ambient temperature up to 220°F, but is available at the preheater outlet at 700-750°F.

Part of the heat from the flue gas can be recovered. In the economic evaluation of the design cases, it was assumed that the gas would be cooled to 300°F, and the heat recovered. The heat recovery can be accomplished in several ways. If the location of the carbon adsorption system is close enough to the bake ovens, part or all of the hot flue gas could be used to heat the incoming air to the bake oven by employing a gas/air heat exchanger.

Another means of recovering the excess available heat is simply to produce additional steam in the incinerator-boiler. The amount of steam in excess of that required in the regenerator could be used in other plant operations such as space heating. Higher pressure and/or superheated steam could be produced separately in the incinerator-boiler, and this could be used to heat incoming air to the bake ovens, particularly if the ovens are located some distance away from the adsorption system.

One of the major problems in recovering the heat, however, will undoubtedly be due to the unsteady solvent output during regeneration of the carbon bed. The solvent concentration in the regeneration stream initially is low, rises to a peak, and then continually declines until the regeneration is complete.

The heat output from burning the regeneration stream varies with the solvent concentration. Methods of reducing the variation in solvent output during the regeneration will be needed if the maximum amount of heat is to be recovered. If steam is produced in parallel with other plant boilers, fuel can be backed out of other boilers to accomodate cyclic operation.

7.0 OTHER CONSIDERATIONS

Some other aspects of the application of carbon adsorption systems to auto assembly plants are considered and discussed in this section. Included are land requirements, plant size, and plant operation.

7.1 Plant Size/Land Requirements

Carbon adsorption systems having the capacity to treat the large volumes of solvent-laden air emitted from auto paint plant operations are physically large. As far as could be determined, regenerable units of over 250,000 scfm capacity have not yet been built or operated.

The solvent recovery system designed for the typical auto assembly plant defined in this report requires approximately 0.5 acre within the battery limits of the unit. The height of the tallest equipment is in the range of 60-70 feet. Finding an area of this size convenient to the painting operations will be a significant problem in many plants where retrofit of carbon adsorption systems is considered.

In some areas it might be more practical to separate the treatment facilities in order to locate them more conveniently. The size of the spray booth treatment systems in almost all cases precludes their installation on or above the roof of the assembly plant close to the solvent-laden air outlet. It is conceivable that the smaller oven control systems could be located on the roof but a considerable amount of structural modification would have to be made to provide adequate support.

7.2 Plant Operations

The operation of a large carbon adsorption system would be a familiar and relatively simple task in a chemical or oil refining plant. In general, however, this is not the case in auto assembly plants. The personnel are relatively unfamiliar with the type of large-scale operations involved, such as adsorption and steam regeneration. It would probably be necessary to assign men solely to operating and maintaining the systems. It was assumed that one full-time operator would be required at all times to operate the system designed for the typical auto assembly plant. In addition, maintenance crews familiar with the plant operation and equipment would be required for both routine and non-routine plant maintenance. Routine maintenance would include replacing air filters and cleaning heat exchangers.

8.0 SUMMARY

The conclusions derived from this study are given in Section 2.0 of the report. Briefly, it appears that the application of large-scale carbon adsorption systems to remove solvents from auto assembly plant painting operations is technically feasible. The cost of this method is estimated to be above that of balance systems for controlling refueling emissions and below those of methods for controlling hydrocarbon emissions from motor vehicles.

The required systems are large. In many cases, they would be larger than any such systems now in existence. In order to obtain detailed and definitive design data, pilot studies would be necessary at the individual plant sites.

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PE-065 Peters, M. S., and Timmerhaus, K. D., Plant Design and Economics for Chemical Engineers, McGraw-Hill Book Company, New York 1968.

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VU-003 Vulcan Cincinnati, Inc., "Solvent Recovery Installations," Sales and Technical Information Brochure.

WO-070 Wohlers, H. C., and Feldstein, M., "Investigation to Determine the Possible Need for a Regulation on Organic Compound Emissions from Stationary Sources in the San Francisco Bay Area," J. of the Air Pollution Control Assoc. 15(5), 226-229 (1965).

Page	Par.	Mechanical Design
45	3)	Shell and tube heat exchangers or fin and tube type?
50	4)	
50	2	There are ways to design using carbon steel vessels, either horizontal or vertical type.
		Layout
62		This layout is too tight. Drawings have been provided to Radian.

Page	Par.	Process Design
34	2	More steam is used (wasted) during the heat up of the vessel and carbon than at the end of the steaming cycle which can be terminated after the "easy" solvent is removed from the bed. Steam is wasted if an effort is made to remove too much of the solvent heel. Certain solvents, such as EtOH, require more desorption steam than others, such as CCl_4. Thick carbon beds, good volumetric use of the adsorber vessel, as in the annular vertical design, and high incoming solvent concentrations, result in the lowest steam/solvent ratios. Sensing breakthrough with an analyzer, then initiating desorption of that adsorber, has proven to be a very efficient way to economize on steam, however, analyzer sensing of solvent mixtures which do not remain constant is not practical.
		Mechanical Design
25	1	Maximum horizontal adsorber size we have provided is 12' Ø x 50' T/T.
25	2	236,000 CFM can be processed in 5 adsorbers or less.
41		Fresh air fan is not practical in a cold climate. It can cause freeze up of a wet carbon bed. Better to take a slip stream from adsorber exhaust. Also, if this blower is required, the flow should be in the same direction as steam, causing vapors to flow to condenser and the condenser should be vented to main blower inlet.
42	3	The adsorber vessel can be fabricated of carbon steel by directing the air flow from inside to outside and steaming outside to inside. If stainless steel is used for internals, chlorides must be kept to a minimum.
42	4	Blower should be of spark resistant construction with TEFC drive. Horsepower should be in the range of 30%, or 50% less than the 2,500 HP drive indicated. Valves specifid are causing too much ΔP.
46	3	The incinerator blower will be in a corrosive atmosphere and carbon steel is not indicated. More $.

VULCAN Cincinnati Inc.

March 10, 1976

Following are some impressions of the Radian study:

Page	Par.	Process Design
6	7	We would expect the steam/solvent ratio to be less than 5:1 and probably 3:1, not 15:1.
20	2	We fail to understand how a water wash system will not remove water miscible solvents from a solvent laden air stream containing water miscible solvents.
27	2	The use of superheated steam to desorb high boilers may not be desirable. Heat transfer from superheated steam, or hot gas, is not good when compared to desuperheated steam which is not practical to use. Carbon will oxidize rapidly in a hot environment. The valves usually provided for solvent recovery systems desorbing with desuperheated steam will not withstand the service if superheated steam is used. More dollars will be added to the cost of the system for valves. Regenerating the carbon off site may be the preferred method.
28	3	Mixed solvents do not necessarily reduce the adsorptive (working) capacity of carbon. Example - Carbon has a working capacity of about 1% for ethanol and about 7.5% for a 50/50 mixture of toluene and hexane.
28	4	This statement refers to only a part of the carbon bed, not the entire bed, i.e., one mass transfer zone. This paragraph could use clarification.
30	4	The conclusion that the deeper a carbon bed the greater the ΔP is correct but not too significant in vertical, annular carbon beds which have an inherent low ΔP. In vertical or horizontal systems the pressure drop through the carbon bed is usually 1/3 to 1/2 the pressure drop of the total system. Deeper carbon beds and the resulting less frequent desorption of the adsorber result in lower steam usage because the sensible heat requirements of the system are satisfied less often.
32	1	Humidity can be too high or too low. Most solvents will be preferentially adsorbed in place of water. The moisture remaining on the carbon bed after steaming serves as a heat sink for the heat of adsorption and this is desirable. Too low humidity dries the carbon bed prematurely and can cause an increase in the oxidation (aging) of the carbon and, in extreme cases where ketones are present, fire may result. Adsorption capacity is lower for hot dry carbon.

Phase VI - Vulcan, in cooperation with the industry, devises log sheets, gathers data and evaluates the performance of the systems.

In this manner, the owner is under no obligation to proceed beyond any phase or, if he wishes, may authorize more than one phase at a time.

The ± 30% cost estimates of the Radian study need refining, as do the process schemes and utility estimates. This suggested program will provide accurate costs, capital and operating, and the process will be demonstrated.

These are our comments and suggestions. We are interested in learning the opinions of those who receive this.

Very truly yours,

VULCAN CINCINNATI, INC.

William R Meyer

William R. Meyer
Manager of Sales,
Environmental Projects

WRM:red

Attachment

cc: Mr. Ron Mueller
United States Environmental Protection Agency
Region IX
100 California Street
San Francisco, California 94111

Mr. M. J. Tyro, Staff Engineer
Plant and Environmental Engineering
General Motors Corporation
General Motors Technical Center
Warren, Michigan 48090

Mr. Victor Sussman, Director
Stationary Source Environmental Control
Ford Motor Company
One Parklane Boulevard
Dearborn, Michigan 48126

value of the recovered solvent will be sufficient to desorb the system and drive the blower, i.e., the system could be nearly self-sufficient for its energy requirements. Capital cost would be increased because of the sophistication of this equipment.

One of the conclusions of this study is that pilot studies be made, however, it was brought out at the workshop that certain studies have already been made.

The subject divides itself into two basic cases: 1) paint spray operations, and 2) baking ovens. There seems little reason not to proceed on a full scale, say 50,000 CFM, demonstration of solvent recovery from bake ovens while the paint spray operation proceeds in pilot stage. This could be worked as a joint industry effort. EPA may be able to provide funds to assist in engineering and equipment procurement for the initial demonstrations and evaluation of the systems. The resulting information would be useful to all involved.

Vulcan's services can be made available in several ways, i.e., for design, for design and supply, and for design, supply and to supervise installation. The total work can be divided into discrete phases with "go-no go" decisions being made between the phases which are identified as follows:

Phase I - Vulcan develops a preliminary design for several alternatives with budgetary estimates.

Phase II - After the preferred alternative is chosen, Vulcan develops a definitive process design, an appropriation type estimate and a detailed scope-of-work.

Phase III - If the cost indicated in Phase II is accepted, and Vulcan is authorized to proceed, the detailed process and mechanical designs and equipment specifications are prepared.

Phase IV - With authorization to proceed with procurement, Vulcan provides the purchasing, expediting and inspection services, preparation of sub-contract bid packages and evaluation of sub-contractors' bids. Orders may be placed directly by Vulcan or for the owner's account at cost, depending on his preference.

Phase V - Vulcan provides competent erection and advisory field services relating to mechanical testing, commissioning and initial operation.

VULCAN
Cincinnati, Inc.

2900 VERNON PLACE
CINCINNATI, OHIO
45219

513 281-2800
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March 10, 1976

Radian Corporation
8500 Shoal Creek Boulevard
P. O. Box 9948
Austin, Texas 78766

Attention: Mr. R. G. Wetherold

Subject: Draft Final Report
EPA Contract No. 68-02-1319
Task No. 46

Gentlemen:

We thank you and the U.S. EPA for the opportunity to participate in the February 26th San Francisco workshop to discuss the subject report. Herein and attached are our comments on the report. We understand that these remarks may be included in the final report or appended to it.

Our general impression is that activated carbon solvent recovery is technically feasible for the auto assembly plant hydrocarbon emissions detailed in the study as long as present EPA solvent regulations, especially the 3,000 lb/day maximum discharge to atmosphere limits, are not tightened up.

Paint spray booth emission control will be difficult to maintain at design efficiency levels for long term operation due to the likely accumulation of undesirable material on the activated carbon and the reduced capacity of the carbon when low solvent concentrations are in the incoming stream.

We question the assumption that the combined desorption steam and solvent vapor can be used directly and continuously as fuel for a waste boiler. About 70% of the system's energy requirement is for the blower which could be driven by a turbine (continuous demand). About one-half of the steam used for desorption will condense during heat-up of the vessel and the carbon, and exit the adsorber through its steam trap. Further, the regeneration of solvent is intermittent and lags the demand for regeneration steam by 20 to 30 minutes. This problem can be resolved but the Radian study does not show the cost of doing it, although it does recognize the need for additional planning in this area. The anticipated Btu

CHEMICAL PROCESS TECHNOLOGY

YORK CHICAGO DENVER LOS ANGELES

98-F

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COMMENTS BY WILLIAM R. MEYER,
VULCAN CINCINNATI, INC.

98-C

RADIAN
CORPORATION

EPA, Region IX - Workshop held on 26 February 1976

List of Attendees

Name	Organization
Ron Mueller	EPA Region IX, Air & Haz. Mat. Div.
Fred Thoits	" " " " " " "
Karen E. Kohnerts	EPA Region IX, Enforcement Div.
Jim Loop	California Air Resources Board
Peter Venturini	" " " "
Bob Roberts	DuPont, Wilmington, Del.
Bob Atkinson	DuPont, Burlington, Cal.
Rod. Buttacavoli	GMC, Assembly Division
Mike Tyro	GMC, Environmental Activities
Bill Meyer	Vulcan Cincinnati, Inc.
Don Lee	Vic Manufacturing Co.
Bill Thurston	EPA Region IX, Enforcement Div.
Martin DeVries	Ford Motor, San Jose, Cal.
Del Twilley	" " " Dearborn, Mich.
Vic Sussman	" " " " "
Dick Hanselman	" " " " "
Jim Kellt	" " " " "
Allen Koeppel	Union Carbide
Bill Krenz	So. California APCD
Gary Kendall	Bay Area APCD
Bob Wetherold	Radian

98.H

APPENDIX A

COMMENTS BY PARTICIPANTS IN WORKSHOP HELD ON 26 FEBRUARY 1976 AT THE EPA REGION IX OFFICES IN SAN FRANCISCO, CALIFORNIA

RADIAN
CORPORATION

COMMENTS BY W. R. JOHNSON, GENERAL MOTORS CORPORATION

GM

Environmental Activities Staff
General Motors Corporation
General Motors Technical Center
Warren, Michigan 48090

March 12, 1976

Radian Corporation
8500 Shoal Creek Boulevard
P. O. Box 9948
Austin, Texas 78766

Attention: Mr. R. G. Wetherold

Re: Radian Project 200-045-46 - "Evaluation of a Carbon Adsorption/Incineration Control System for Auto Assembly Plants"

Gentlemen:

As requested at the EPA, Region IX, sponsored Carbon Adsorption Workshop held in San Francisco, California, on February 26, 1976, General Motors is submitting comments relative to the subject Radian project report.

General Motors agrees with the concept that a carbon adsorption system has potential application in controlling solvent emissions from automotive assembly plant paint spray booths and bake ovens. We also agree on the importance of pilot studies to distinguish in-use feasibility from theoretical feasibility.

Our comments are not intended to discredit the Radian report but to bring into perspective the potential complexities of installing and operating a carbon adsorption system at an automotive assembly plant. The views expressed herein were either overlooked or treated lightly in the report and should be considered before any final decision is made as to the technical and economic feasibility of a carbon adsorption system as it relates to controlling paint solvent emissions from automotive spray booths and ovens.

It is acknowledged that activated carbon can be efficiently utilized to adsorb solvents and be desorbed or regenerated effectively with steam or by other methods. Treating the total exhausted air from spray booths and ovens can reduce hydrocarbon (solvent) emissions by approximately 90-95 percent if the carbon adsorption system is properly engineered initially and regularly maintained.

Various automotive paint operations have total exhaust air, containing hydrocarbons, that range from one million to two million cubic feet of air per minute. Since carbon adsorption systems are designed according to the air volume to be handled, this can result in enormous sizes of equipment with space requirements that most plants will be unable to provide.

Radian's report circumvents this problem of massive air handling by stating, or mostly inferring, that only a portion of exhausted air from each source could be treated to attain the maximum 3,000 pound limit imposed by Rule 66. This scheme would be impractical since it is based on two false assumptions. One is that the 3,000 pound limit is permanent. As stated at the workshop, much lower limits are being considered. Secondly, that hydrocarbon concentrations remain constant from selected exhaust stacks. This is rarely the case because of spray booth design and the nature of painting operations.

There are other factors, either absent or briefly stated in the report, which must be resolved. Some of these are:

1. Safety requirements - OSHA, NFPA, FMI, etc. have codes for the protection of workers against fires and potential explosion hazards. These, or similar codes, may restrict the use of carbon adsorption systems for solvent collection as designed for assembly plant paint operation.

2. Instrumentation and controls - reliability and availability requirements must be determined.

3. Backup equipment - required in case of failures or breakdowns. Note: Recently proposed Rule 430 by the Southern California Air Pollution Control District requires notification to the District within 30 minutes of an emission control equipment breakdown; operation of equipment only until end of run or 24 hours, whichever occurs first, then it shall be shutdown; if beyond this limitation, a petition for an emergency variance must be filed. Without such equipment, significant delays and possible indefinite shutdowns of manufacturing facilities will occur.

4. Natural resources - carbon adsorption systems increase demands on the availability of electrical energy, natural gas, and oil.

5. Battery limits - the ideal conditions upon which the design criteria and cost figures are based are virtually non-existent at assembly plants.

In addition, there are other operational aspects of a carbon adsorption system that must be considered and resolved. They are:

a. Pre-filtration of air streams

b. Temperature and humidity controls

c. Fouling of condensers and heat exchangers

d. Noise problems with fans, blowers, etc.

e. Engineering design of valving, locations, booth and oven modifications, etc.

We believe that the factors enumerated demonstrate the complexities and unresolved problems associated with the feasible technology of a carbon adsorption system at an automotive assembly plant. To avoid inefficiencies, duplications, and costly mistakes, further research and development work, including practical experience, are required.

Very truly yours,

W. R. Johnson

W. R. Johnson, Director
Plant & Environmental Engineering

MJT:pmm

COMMENTS BY V. H. SUSSMAN,
FORD MOTOR COMPANY

V. H. Sussman, Director
Stationary Source Environmental Control
Environmental and Safety Engineering

Ford Motor Company
One Parklane Boulevard
Dearborn, Michigan 48126

March 15, 1976

Mr. R. G. Wetherald
Radian Corporation
8500 Shoal Creek Blvd.
P.O. Box 9948
Austin, Texas 78766

Dear Mr. Wetherald:

In accordance with your request at the February 26, 1976 meeting, the following is an outline of our comments in the order (according to my notes) in which these points were discussed.

- In this instance, the use of battery limits data in developing and presenting cost information is inappropriate and misleading. Everyone at the meeting agreed that these systems would have to be tailormade to meet specific physical and process differences at different plants. Such modifications are much more significant in cost evaluations than battery limits considerations. We pointed out that, e.g. for a 450,000 CFM "Base Case" system, we believe that a bare bones cost (i.e. not including humidity, safety and fire control) would be $9.5 million -- compared to the report's $2,763,500 estimate for a battery limits system. This higher price does not assure that further development will not be required on parts of the system or that equipment suppliers would adequately guarantee the removal efficiency of a system as large as 450,000 CFM. Based upon actual engineering designs we have performed, we believe that the difference between battery limits and actual installed system costs can vary greatly depending upon such factors as:
    - o incoming electric service, breakers, transformers, water lines, sewers, cooling tower systems;
    - o site preparation;
    - o the cost of duct work from the individual booths and ovens to the filters. Recent design experience we have had indicates that a careful analysis must be made of whether the several exhaust from any booth or oven can be intermingled ahead of the final exhaust to the atmosphere;

o the cost of interferences, construction delays, overtime for final connections and engineering.

I indicated during the meeting that it appears that the unit prices for fans, boiler/incinerators, control valves and filters appear understated for the quality of hardware normally installed at Ford plants.

- The report did not indicate the criteria used in defining "technical feasibility." Almost anything is technically feasible, especially (as I pointed out) to the person who doesn't have to do it. Also, technical feasibility could be defined as what a handbook on physical chemistry reports on the potential of various hydrocarbons with respect to adsorption on and desorption from carbon. Without a clear definition of "technical feasibility," the report's conclusions cannot be objective.

- Every place in the report where it is indicated that the proposed system is technically feasible and/or economically reasonable, a statement should be made to the effect that this conclusion is based upon the existence of a Rule 66 "3,000-pound-per-day limit." As indicated by Bill Krenz, it is almost certain that the report's conclusions would be significantly different (and, in fact, a completely new evaluation would be warranted) if the 3,000-pound limitation were not a prime assumption. I stated that there was some question as to the regulatory acceptability of the report's assumptions concerning the manifolding of some of the units to be controlled. It is questionable as to whether or not a regulatory agency would permit such manifolding since compliance with emission limitations could not be determined.

- There was considerable discussion concerning particulate removal requirements. We showed slides of our Louisville pilot filtration unit and outlined some of the factors which makes this a major consideration. The removal of paint particulate matter by filtration prior to the adsorption stage will be much more costly and complicated than suggested in the report.

  Ford has prepared some concept drawings of carbon adsorption systems for spray booth emission controls at a specific plant location. One basic requirement in the Ford design placed the particulate filters as close to the sources as practical. This approach is taken to insure a "clean" system of ductwork leading to the adsorber and to minimize costly cleaning requirements, reduce safety hazards and structural liability for the large size ducts involved. Radian concluded that paint particles are "dry" and can be collected in "disposable fiberglas bag filters" with bag replacement on a monthly basis. Without additional prefiltration, such a system would be impractical.

With respect to oven emissions, particulate removal prior to adsorption and problems resulting from particulate formation on the carbon bed were discussed. We believe that the Radian report does not sufficiently address this issue as well as the issue of the extensive refrigeration equipment required to cool exhaust gas prior to adsorption.

Ron Mueller asked if we are planning to provide any filtering equipment for the new catalytic oven incinerator installation at Los Angeles. Filtration is not required, because there is no particulate matter. Emissions are kept in the vapor state and pass through the burner where they are raised to a temperature of 800° F. at which point oxidation can take place in the platinum impregnated bed.

- Along with our discussions of particulate removal, other issues related to "exhaust gas conditioning" were also noted.

  Except for the brief discussion on page 32, the report did not give adequate consideration to problems of humidity. Paint spraybooth exhaust passes through a waterwashed back section in order to remove entrained particulate matter. Measurements made at typical Ford plants and observations made on roofs of assembly plants indicate that the exhaust gases exit the plant at or near saturation. On particularly cold days, when cooling of the gases takes place in the stack itself, entrained moisture is observed. In view of the possible deterioration of the carbon adsorption operation, some consideration must be included in the design to maintain humidity control below 80%. During periods of cool ambient temperatures (less than 70° F.) exhaust gas cooling accompanied by saturation of the exhaust is highly possible particularly when extremely long duct runs are used to carry the exhaust gas to a battery limit adsorption plant. Cost for humidity control could be significant where extremely large air flows are involved.

- During Bill Meyers' discussion of large adsorption installations, we raised questions on certain design parameters.

  o Although Bill indicated that such installations are possible, we believe that it is important to recognize some of the significant design problems involved. For example, the applicability of a tall vertical annular bed as proposed for the spraybooth systems is questionable. A 45-foot tall annular column of carbon could produce considerable forces at the base of the column. This could cause carbon breakup or attrition resulting in increased packing density, loss of carbon material, and high pressure drops. The variation in packing density due to the extreme bed heights would likely produce nonuniformity in flow through the carbon bed due to the various degrees of bed void space. This could result in significant loss of adsorptive capacity and possibly increased pressure drop throughout the system. It appears that consideration of carbon adsorption configurations was limited and arrangements were not optimized. (I would like to re-emphasize that the importance of insuring uniform air flow through the spraybooth, in to protect workers and meet OSHA requirements, was not recognized in some of the proposed systems. The balance of air flow in a spraybooth system could be greatly affected by discharging some portions of the booth to the atmosphere and others to a pressurized system.)

- The use of a design gas velocity of 110 feet/minute at the bed inlet face appears high. This design velocity would in actuality produce a face velocity leaving the bed of 126 feet/minute and could be sufficient to produce carbon attrition, severe bed packing and high pressure drop. Lower design gas velocities on the order of 80 feet/minute would be more realistic. This, of course, would result in significantly larger carbon beds to accommodate the exhaust air flow.

- The use of 300 ppm as a typical oven concentration is excessive. For Ford applications 50 ppm as toluene would be more realistic.

  While discussing solvent concentration, it should be noted that care must be exercised in using data from published sources concerning hydrocarbon emissions and/or control equipment efficiencies to insure that the basis for measurement is stated. In most cases the measurement of emissions and/or the control equipment performance is based on some type of hydrocarbon analysis using instruments calibrated against standard gases. As such, the concentrations measured are in actuality related to some standard gas such as methane or propane. A measurement of 300 ppm as methane would be equivalent to 50 ppm as hexane or 43 ppm as toluene. In view of this, it is important when citing hydrocarbon concentrations to indicate the basis for the values.

- During our presentation on the Ford pilot carbon adsorption study (an outline description of the study, test results, observations and conclusions was sent to you with my letter of February 18, 1976), the following points were discussed:

  - Oven Tests -- We stated that using the shallow 4" bed in our test equipment did not achieve the desired 85% reduction. We concur that a deeper bed would meet this requirement; however, the necessity for cooling the stack discharge allows condensation to occur and contaminants will drop out and deposit on cooling tubes or on the filter media, which creates horrendous disposal problems.

    By operating in the incineration mode, we are back to what we originally tried to avoid -- the use of an incinerator. The difference in fuel consumption between a full size oven incinerator and a somewhat smaller and intermittently operated carbon adsorption incinerator does not offset the other installation and operation problems in utilizing a carbon adsorption system for ovens.

Operating in the condensate mode creates an even more difficult problem in disposing of objectionable solvent mixtures and the contaminated steam condensate. Again, these problems of disposal and potential water pollution more than offset the advantage of using this system.

Don Lee of Vic raised the question as to whether our test carbon bed had not deteriorated as a result of the booth test and therefore did not give us optimum results in the oven test. I believe our Comments and Observations answer this question. As indicated, the bed was completely regenerated by the use of super-heated steam; even to the extent of using a minus 20" WC vacuum pump to insure that the carbon was as good as new.

The question of bed life was also discussed. This probably would be one of the more significant issues to be resolved by the proposed pilot test. An important factor in considering bed life is that high boiling organic vapors cannot be completely removed from the oven air simply by cooling to 100° F. Some of these materials are transferred to carbon as aerosol particles. The high boiling materials cannot be desorbed by use of steam. Even though the concentration of high boiling materials in the air stream is small, the total cumulative amount is sufficient to deactivate carbon rapidly.

(Again, I think it is important to point out that -- (1) We have had more experience than anyone else in actually testing these units on automotive painting operations, and (2) If we had believed that carbon adsorption had potential as a practical means of meeting Rule 66 oven requirements, we would not be continuing to use afterburners. As you will recall, we indicated at the meeting that we are presently installing a catalytic afterburner as a replacement trial on one of our ovens in Los Angeles.)

- Aside from the obviously fallacious approach of basing costs on battery limit plants designed to limit emissions to 3,000 pounds per day, other questions were raised with respect to the "Process Economics" section.

  o Credit is taken in the operating cost of the system, for available heat in the recovered solvents. This did not appear to be feasible in the Ford study. The collected solvent vapors are desorbed in an "avalanche" and(cannot be stored so that)the heat from the solvents is not available at the time it is needed in the carbon regeneration cycle.

  o Reducing costs to cost per unit is fallacious and meaningless. The report's operating cost of $1.5 million per year is projected to a cost of $3.50 per car. For our San Jose Assembly

Plant, this unit cost is over $9 per vehicle at present production schedules. This is another example of unqualified, meaningless statements in the report.

- There are various estimates similar to the table on page 81. The "$/Ton Controlled" depends upon whether you are starting from an uncontrolled source or increasing the efficiency of existing systems. There is considerable disagreement regarding the control costs listed for a number of the sources in the table -- and we take particular exception to the Radian report's estimate.

- Some minor points:

  - On page 11 the solvent emissions from spraybooths and ovens indicates a ratio of approximately 3:1 respectively. Our measurements on typical Ford enamel and prime spraybooths and ovens indicates a relationship approaching 9:1. In the L.A. and Bay areas, I assume many ovens already have emission control devices in order to comply with existing regulations. Taking this into consideration the current expected emission ratio would be well in excess of 9:1.

  - On page 13, Table 3.2-1 contains a typical breakdown of solvent types of various types of coatings. The table does not appear to reflect typically exempt enamels currently in use in many areas of the country; too much aromatic compound is present. On the basis of typical Ford exempt paints, a more likely breakdown of solvent content would be:

Aliphatics	21%
Aromatics	11%
Alcohols	10%
Ketones	6%
Esters and Ethers	5%
Nonvolatiles	47%

  - First sentence, second paragraph, page 20 -- face velocities should be stated as ft^3/min per square foot.

In conclusion, I would like to make some general comments about this report:

- The report contains a number of gratuitous and cursory comments on the need for solvent control and the applicability of Rule 66. (The work statement for this project did not call for addressing these issues.) If these issues were believed important enough to be included, then a more complete and detailed discussion should have been presented. For example:

  - In the outline of the provisions of Rule 66; why wasn't the basis and meaning of the emission standards discussed? The

3,000 lb/day limitation is a key factor in the report's evaluation of the required degree (and thus cost) of control.

- In the section on the need to control organic emissions; why wasn't hydrocarbon reactivity, seasonal variability or intermittent control (if I am allowed to use this term) discussed? Why wasn't the adequacy of the Bay Area Air Pollution Control District's regulations (as opposed to Rule 66) in meeting the "TCP hydrocarbon roll-back task" discussed?

It is the presence of these superficial "throw away" statement -- not only in the introduction, but also (as I have indicated) in latter sections on particulate removal, stack gas conditioning, heat recovery, separation of stack gas streams, safety requirements, novelty of technology, etc. - that brings into question some of the report's unqualified conclusions. It would seem that some of these issues should have received treatment at least equal to the presentation on the mechanics of adsorption.

- Some recognition is given (last paragraph, page 96) to the fact that there may be some problems involved in building and operating these units -- and thus "pilot studies would be necessary." The report does not indicate what specific open issues should be resolved by such pilot studies. In general, it is the open issues that the report does not adequately identify and address.

Sincerely,

Victor H. Sussman

cc: G. Kendall
W. Krenz
D. Lee
W. Meyer
R. Mueller
F. Thoits
M. Tyro
P. Venturini

///

RADIAN
CORPORATION

COMMENTS BY DON LEE,
VIC MANUFACTURING COMPANY

VIC MANUFACTURING COMPANY
1620 CENTRAL AVENUE N.E., MINNEAPOLIS, MINNESOTA 55413/PHONE (612) 781-6601

AIR POLLUTION CONTROL SYSTEMS

March 17, 1976

Mr. Bob Wetherhold
Radian Corporation
8500 Shoal Creek Blvd.
Austin, Texas 78766

RE: Carbon Adsorption Workshop
E.P.A. REGION IX
E. P.A. Regional Office
San Francisco, CA

I. Comments on Activated Carbon - Incineration, General

Activated Carbon Adsorption is an engineering tool. It is but one of a number of methods that an engineer must weigh to determine the best approach on tackling any problem. Adsorption systems seem to work the best when other methods are either impossible or too expensive. Such is the case when a solvent is very dilute in an air stream. Condensation becomes next to impossible and incineration gets exceedingly expensive because it is required to heat too much air in the process. Activated carbon adsorption is not a method of disposal of a pollutant unless, of course, you want to take it out and bury it someplace. It should be thought of as a method of accumulating and concentrating of a pollutant so that it can be recycled or disposed of in some other way.

The carbon-incineration concept is merely a combination of two different systems - one to accumulate, one to dispose of the pollutant. The energy value of the solvent is a bonus in these applications. The main economy of such a system is in its ability to handle highly dilute applications.

There has been considerable experience on handling baking oven exhaust. There has been less experience on handling air from spray paint operations. In almost all of these applications, there is a limited bed life of the activated carbon. This is because of the buildup of particulate matter, high boiling compounds, or resins that may bake off at high temperatures. In most cases this bed life will run anywhere from six months to six years. As such, the activated carbon system must be sized for a declining capacity, and the activated carbon must be reactivated at such time as the bed is no longer functional. This involves some extra expense, but not prohibitive. It should be kept in mind that activated carbon is used in "Tertiary" sewage treatment at Lake Tahoe, wherein the activated carbon is reactivated through a furnace on every cycle.

II. Comments on Ford Report

As brought out in the meeting, Ford Motor Company tested a pilot VIC unit at the Michigan Truck Plant in Warren Michigan for approximately 2 years. This happened to be a "canister bank" system, which is one of several designs employed to allow a maximum air handling capacity per system, and thereby bring down the total cost per CFM. Supposedly information from such tests would be a further guide as to air handling capacity, efficiency, etc. The pilot was provided with a tray mechanism where different types of prefiltration media could be tested. It was necessary to come up with the proper type of media before putting it through the carbon system to assure that it would operate properly, as such studies were done on prefiltration media, the activated carbon system, and the incineration boiler unit that was also provided with the system.

SPRAY PAINT - EXHAUST

For most of the test period involved, exhaust from spray paint booths were tested. We were gratified to find that many types of filter media would do a good job at this location with comparatively good life. Initial tests on the solvent indicated that efficiencies of 85% to 95% (typical of Canister Tank Systems) could be obtained over an initial 14 hour period. A declining bed capacity would affect the cycle time and it could be reduced all the way down to a minimum of 1 hour. It was felt that the initial tests were successful.

Apparently, additional tests were done in Louisville, Kentucky under a much more humid condition. This was done on the prefiltration of the particulate matter only and carbon was not involved. From the comments made at the meeting, it would appear that the prefiltration can be done, but here again it's a matter of expense. The prefiltration problem is something that would probably vary considerably from location to location. The fact that the filter media became quite wet at Louisville would probably indicate looking into other types of particulate filtration involving methods other than entrainment.

Baking Oven Exhausts:

Baking oven tests were conducted later on and frankly we never did get much data back on it. However, the efficiencies that Ford experienced are not typical, and two things remain unanswered, which are critical to the performance of the system.

1. I doubt very much if the air was ever cooled sufficiently to do a good job on the solvent. The air must be cooled to temperatures below 100°F. to give us a sufficient working capacity and efficiency.

The last visit I made to Warren, Michigan indicated that the type of cooling system that was used never got the temperature below 114°F. It may be possible that lower temperatures were obtained at a later date. It must be kept in mind to obtain a proper working system, these temperatures must be consistent, and over a long period of time to allow the "Adsorbed Heel" on the carbon bed to come to an equilibrium. This won't be accomplished with one day or even several days of lower temperatures.

2. There's no indication that the activated carbon in the system was ever renewed nor tested prior to conducting the baking oven tests. Since the spray paint exhaust tests were conducted for almost 2 years under a variety of conditions, there is a very good possibility that the carbon became somewhat spent. To eliminate this as a variable, new carbon should have been put into the system prior to conducting the baking oven tests. We have many successful baking oven exhaust applications operating presently. These are from a variety of applications, but the problems remain somewhat the same -- that is, temperature and bed loading. I would say that most of these applications were more critical from the standpoint of quantity of high boiling compounds and loading factors. All of them have to reactivate the carbon periodically. All of them have proven to be less expensive than other methods of doing the same thing.

SURGING

Ford expressed a problem in that the solvent had a tendency to surge during the regeneration, thereby, causing an uneven supply of fuel to the incinerator boiler. This is absolutely true, although there are a number of ways to flatten out these up and down fluctuations. This only occurred when we were trying to incinerate the steam solvent vapors directly without condensing. Many people prefer to condense the vapors, and then use the liquid directly as a fuel in a boiler or burn the total liquid,water, and solvent in a liquid incinerator. This not only allows you to eliminate any surging effects, but it also allows you to use the liquid when and where it makes sense. I think one of the more important things that came out of the Ford test, as far as incinerating the vapors were concerned, is that the incinerator apparently did a good job, whether there was a surge or not. The company that built the incinerator part of the equipment did tests on the exhaust during the operation.

SIZE

Ford brought up the argument that there never has been any system quite this big built, and the physical size of a proposed system was somewhat overwhelming. They're probably right as far as overall size is concerned, but there have been systems built handling 100,000 - 200,000 C.F.M. There is no reason why a number of these systems wouldn't do the same job. In fact it's been proven on a number of different types of equipment that once you get to a certain size, it's easier to handle the problem with several small systems than on big system. There is a point of diminishing returns when it comes to designing one large system to handle the whole thing. There are a number of arguments for a number of small systems versus one big system:

1. The weight involved in handling various integral parts, such as blowers, adsorbers, ducts, dampers, etc.
2. The number of smaller modules gives you considerable flexibility during temporary shutdowns for repairs, maintenance, etc.
3. Parts are more easily replaced. Smaller modules can be built at a factory and shipped to the job site, whereas larger systems may have to be built at the job site at considerably more expense.
4. Maintenance is easier on smaller systems.

It might also be pointed out, this would be a large application, no matter what method they went to, incineration, water base systems, etc.

III. Conclusion

We also feel that the Radian Report is very realistic, Much more comprehensive than any similar report I have seen. It appears that the main argument between the Radian Report and the Ford Report is that of cost. Both seem to agree that the carbon system does work technically. Our experience, based on dollar per CFM, as to installation cost and operational cost, would lean more towards the Radian Report.

The main thing to be determined here is whether Ford has to solve the problem. At least half of our baking oven applications now existing in the field were installed because of air pollution and not because of some economic return. If Ford or anybody else has to resolve an air pollution problem, then adsorption-incineration systems will have to be considered on their own merits versus the cost of doing anything else. At VIC we feel that activated carbon adsorption is one of the better methods, and one of the least expensive methods. This idea is shared by many others.

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DL:pe

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